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APPLIED PHYSICS
FOR AIRPLANE MECHANICS

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APPLIED PHYSICS FOR AIRPLANE MECHANICS

SECTION I

APPLIED MECHANICS

1. **Force.**—*a. General.*—Force is the action of one body on another tending to change the state of motion of the body acted upon. Force may tend to move a body at rest. It may tend to increase or decrease the motion of a moving body or change its direction of motion. The application of force also may result in one or more of the following states of stress in the body acted upon:

(1) Tension (tendency to make longer or stretch), as in the control cables on an airplane.

(2) Pressure or compression (tendency to shorten or narrow), as on the under surfaces of a wing during a banking maneuver.

(3) Shear (tendency to cut a body by the action of two parallel forces), as in a shaft under a load (example, an automobile axle) or the shearing of a rivet.

b. Measurement.—A force can be measured in three ways: by the weight it can support, by its ability to stretch an elastic body (such as

a spring), and by its ability to move a body. In aircraft mechanics, force is ordinarily measured in pounds. Less commonly used units of measurement are the gram ([1 gram (g. or gm.) = 0.0353 ounce]) and the kilogram (1 kilogram = 2.204 pounds). Many different instruments have been designed for both manual and automatic measurement of force in aircraft.

c. Resultant forces.—If a force or forces are applied to a moving body, the body will tend to move at a different speed or in a different direction, or both. The force resulting from the combined action of two or more forces is called the "resultant."

(1) If two forces applied to a point act in the same direction, the resultant will be a force equal to the sum of the two forces and will act in the same direction. Thus, if a northward force of 10 pounds and a northward force of 15 pounds act on a point, the resultant will be a northward force of 25 pounds.

(2) If two forces applied to a point act in opposite directions, the resultant will be a force equal to the difference between the two forces and will act in the direction of the larger force. Thus, if a northward force of 10 pounds and a southward force of 15 pounds act on a point, the resultant will be a southward force of 5 pounds.

(3) If a force is applied to a point at an angle to another force acting on the same point, the resultant will be a force of a magnitude that depends on the size of the angle between the two forces and on their magnitudes. This resultant will act in a direction nearer that of the larger force. The direction and magnitude of the resultant can be determined graphically by representing the two forces as adjacent sides of a parallelogram, with the length of the sides drawn in proportion to the magnitude of the forces. The length of the diagonal of the parallelogram will represent the resultant. Thus, in figure 1 ①, the

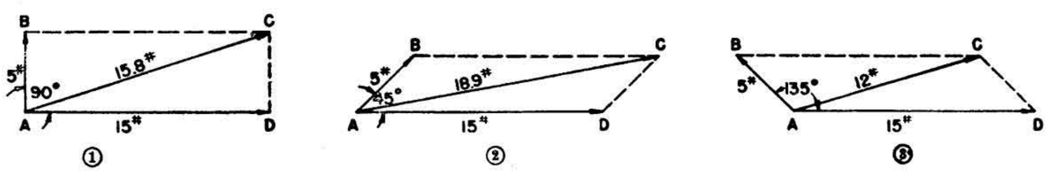


FIGURE 1.—Resultants.

resultant of force AB (5 pounds) and force AD (15 pounds) meeting at right angles is a force of about 15.8 pounds acting in the direction AC. In figure 1 ②, in which forces AB and AD act at an angle of 45°, the resultant acts in a different direction and is of greater magnitude than in figure 1 ①. In figure 1 ③, in which forces AB and AD act at an angle of 135°, the resultant acts in still another direction and is of smaller magnitude.

2. Force of gravity.—*a. General.*—Every body of matter in the universe attracts every other body with a certain force. This force is called "gravitation." The term "gravity" is used to refer to the force which tends to draw all bodies toward the center of the earth. The weight of a body is the resultant of all gravitational forces acting on the body.

b. Center of gravity.—Every particle of an object is acted on by the force of gravity. However, in every object there is one point at which a single force, equal in magnitude to the weight of the object and directed upward, can keep the body at rest—that is, can keep it in balance and prevent it from falling. This point is known as the "center of gravity." The center of gravity might be defined as the

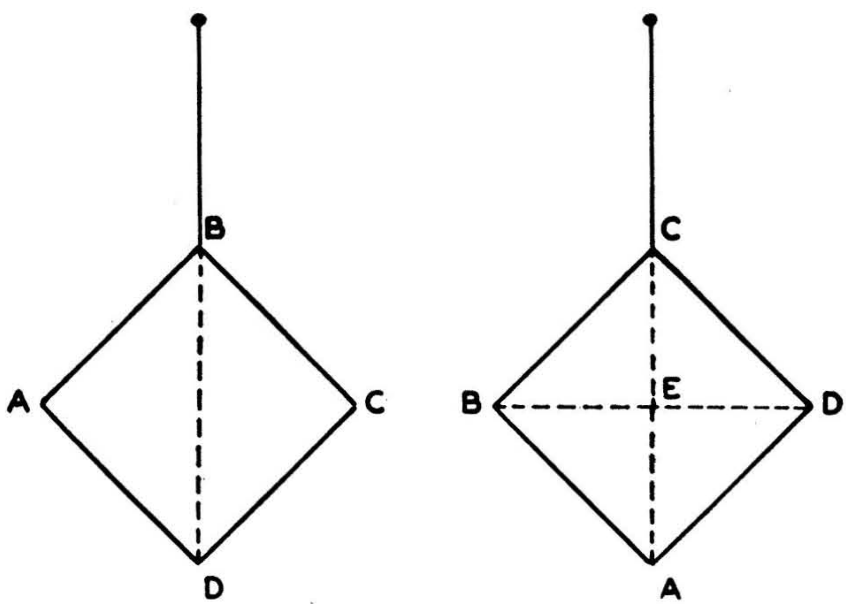


FIGURE 2.—Location of center of gravity.

"point at which all the weight of a body may be considered concentrated." Thus, the center of gravity of a perfectly round ball would be the exact center of the ball, and the center of gravity of a ring would be the center of the ring—not any point in the ring itself. Likewise, the center of gravity of a cube would be a point within the cube equidistant from all eight corners. In airplanes, ease of control and maneuverability depend partly on the location of the center of gravity.

c. Location of center of gravity.—Since the center of gravity of a body is that point at which its weight may be considered to be concentrated, the center of gravity of a freely suspended body will always be vertically beneath the point of support. To locate the center of gravity, therefore, it is necessary only to determine the point of intersection of vertical lines drawn downward from two points of support on the body. Thus, in figure 2, if the flat object ABCD is suspended

first from point B and then from point C, the intersection E of the lines BD and CA is the center of gravity. The center of gravity of any irregular three-dimensional body could be determined in the same way.

3. Laws of motion.—*a. Inertia.*—An object at rest tends to remain at rest, and an object in motion tends to remain in motion in a straight line, unless an external force is applied to change the state of rest or motion of the object. Inertia is *that property of an object which tends to keep it at rest or in motion in a straight line.* Thus a stationary airplane remains stationary until force is applied to move it, while a gliding airplane tends to keep gliding until the force of friction with the air, gravity, and other forces end its flight. Force is always required to change the state of motion of any body.

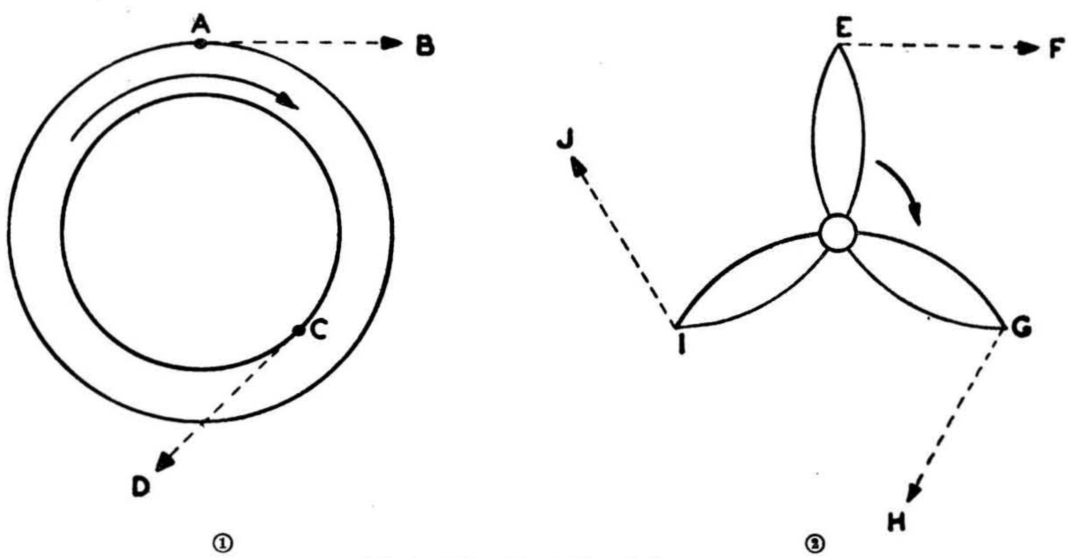


FIGURE 3.—Centrifugal force.

b. Centrifugal force—definition.—The tendency of a moving body to keep moving in a straight line is the reason an airplane "skids" when making an improperly banked turn, why mud flies from a rotating automobile tire, etc. All parts or rotating objects are subject to this force, which is known as "centrifugal force." Centrifugal force may be defined as the "force with which any part of a rotating body tends to fly outward at a tangent to the circle of its rotation."

(1) *Examples.*—Centrifugal force is present in a whirling flywheel or a rotating propeller. In figure 3① the point A on the revolving wheel tends to fly outward along the tangent AB, while the point C tends to fly outward along the tangent CD. In figure 3② representing a rotating propeller, the point E tends to follow the tangent EF, G the tangent GH, and I the tangent IJ.

(2) *Magnitude.*—Rotating parts which are fixed cannot fly outward; therefore, stresses due to centrifugal force are set up within them. The greater the speed and the greater the weight of the rotating part, the greater the centrifugal force exerted. Thus, in figure 3① point A moves faster than point C because it is farther from the axis of rotation; hence the centrifugal force at point A is greater than that at point C. Many parts of aircraft, such as the propeller hub, are subjected to centrifugal loads. These parts must have great strength in order to withstand the loads exerted.

c. Momentum.—The quantity of motion possessed by a moving body—that is, the force with which it moves—is its "momentum." The momentum of a body is equal to the product of its mass (weight) and its velocity (speed); or, in the form of an equation:

$$\text{Momentum} = \text{mass} \times \text{velocity}.$$

Thus a body weighing 10 pounds and moving at the rate of 10 feet per second has a momentum of 100 pounds-feet per second.

4. Work.—*a. General.*—Any force which changes the state of motion of a body is performing work upon that body. The amount of work accomplished is equal to the product of the force applied to the body and the distance through which it is moved, providing the displacement is in the direction of the force. Thus, if a body weighing 2 pounds is lifted 8 feet, 16 foot-pounds of work is done. If a force acts upon a body at rest without moving it, no work is said to be done (although it may be said that a force is exerted on the body). When a body is being moved across a horizontal plane, the only work done is the work necessary to overcome the friction between the body and the plane.

b. Measurement.—In aircraft mechanics, the inch-pound and the foot-pound are the commonly used units for measuring work. An inch-pound is the work done by a force of 1 pound acting through a distance of 1 inch, and a foot-pound is the work done by a force of 1 pound acting through a distance of 1 foot. A mechanic who lifts a weight of 50 pounds to a height of 3 feet accomplishes 150 foot-pounds of work.

5. Efficiency.—*a. General.*—No machine operates with perfect efficiency. In all machinery, the work expended is always greater than the work accomplished, because some of the work is converted into heat by friction, compression, and collision among the parts. The efficiency of a machine is the ratio of the total work accomplished to the total work expended, thus:

$$\text{Percent efficiency} = \frac{\text{work accomplished (output)} \times 100}{\text{work expended (input)}}$$

b. Efficiency of some simple machines.—Machines vary a great deal in efficiency. A simple lever, in which the friction of the lever against a knife-edge fulcrum is very small, may have an efficiency of nearly 1; that is, it may be almost 100 percent efficient. The common block and tackle with several pulleys may have an efficiency of only 40 to 60 percent, much of the work expended being wasted in overcoming the friction of the rope on the pulleys and of the pulleys on their axes of rotation. A system of gears may have an efficiency as high as 95 percent. Heavier and more complicated machinery, such as steam and internal-combustion engines, is much less efficient because of the large amount of work converted into heat by friction and compression.

6. Pulleys.—*a. General.*—The use of pulleys to facilitate the accomplishment of work is familiar to everyone. A pulley system is

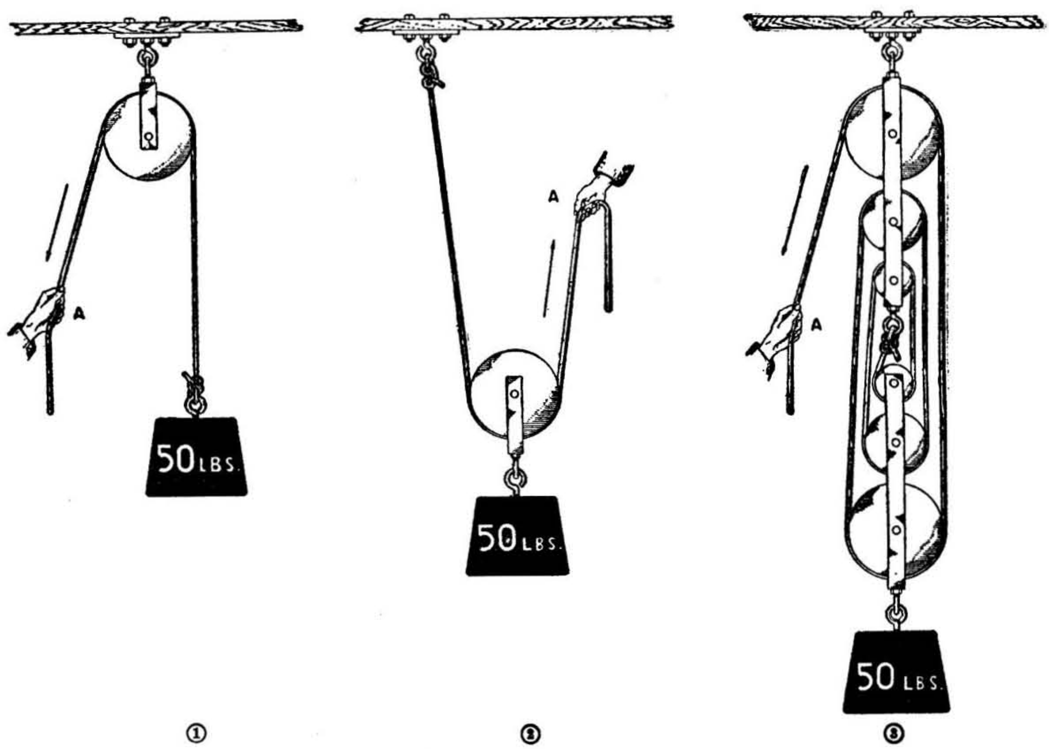


FIGURE 4.—Pulleys.

a device by which a given force can be increased by reducing the distance through which it operates, or vice versa. In other words, by means of a pulley system, force can be increased at the expense of distance, or distance at the expense of force. The total amount of work, however, remains constant. Thus, a man lifting a weight of 50 pounds to a height of 1 foot with his hand must exert a force of 50 pounds and does 50 foot-pounds of work. The same man, by using the single movable-pulley system shown in figure 4②, could lift

50 pounds 1 foot by exerting a force of 25 pounds through a distance of 2 feet, in which case he would still be doing 50 foot-pounds of work. By using several pulleys in a single system, a large force can be exerted through a short distance by the exertion of a small force through a long distance, or vice versa. In aircraft, the principle of the pulley is used in the automatic pilot for moving the control surfaces, etc.

b. Examples.—In figure 4①, note that a force of 50 pounds must be applied downward at A to lift the weight of 50 pounds, which moves through the same distance as the force exerted. In figure 4②, a force of 25 pounds applied upward at A will raise the weight a distance equal to half the distance through which the force is exerted. In figure 4③, a force of 8⅓ pounds applied downward at A will raise the weight a distance equal to one-sixth of the distance through which the force is exerted. In all three cases, the total amount of work done remains the same (force exerted × distance exerted; or, weight moved × distance moved).

c. Efficiency.—In the examples just given, perfect efficiency of the pulley systems was assumed. Actually, the force of friction and the force required to overcome the inertia of the stationary weight would necessitate the application of a greater force to do the work.

d. Mechanical advantage.—When, as with a pulley system, a force is used to overcome a larger resisting force, a *mechanical advantage* is said to have been gained. Mechanical advantage is equal to the resistance overcome divided by the force exerted. Thus, the theoretical mechanical advantage (ignoring friction) of the single fixed pulley is 1; of the single movable pulley, 2; and of the combination of six pulleys, 6. If, in figure 4③ the weight were placed at A and the force exerted where the weight is now attached, the mechanical advantage in force would be 1/6, since a force of 300 pounds would have to be exerted to lift the weight (through a distance six times the distance through which the force was exerted). If distance or speed is gained instead of force, the mechanical advantage is equal to the distance the resistance is moved divided by the distance the effort moves.

7. Levers.—*a. General.*—Like the pulley, the lever is used to gain mechanical advantage—to gain force or distance, one at the expense of the other. A lever is essentially a rigid rod free to turn about a point P called the "fulcrum." (See fig. 5.) Wrenches, crowbars, and scissors are examples of levers.

b. Classification of levers.—There are three types of levers. In the first type (fig. 5①), the fulcrum P is located between the applied effort E and the resistance R. In the second (fig. 5②), the resistance R is between the fulcrum P and the effort E. In the third (fig. 5③),

the effort E is between the resistance R and the fulcrum P. Note that in figure 5① the nearer the resistance is to the fulcrum, the less will be the effort required to overcome it; and the farther the resistance is from the fulcrum, the more will be the effort required to overcome it. The same is true in figures 5② and 5③. Figures 5① and 5② represent types of levers with which force is gained at the expense of distance, while figure 5③ represents a lever with which distance is gained at the expense of force.

c. Moments—definition.—If, in figure 5①, the resistance R equals 4 pounds and it is 2 inches from the fulcrum P, and if the effort E is applied 8 inches from the fulcrum, it will be found that an effort of 1 pound will balance the resistance R. In other words, when a lever is balanced, the product of the effort and its lever arm (distance from the fulcrum) equals the product of the resistance and its lever arm.

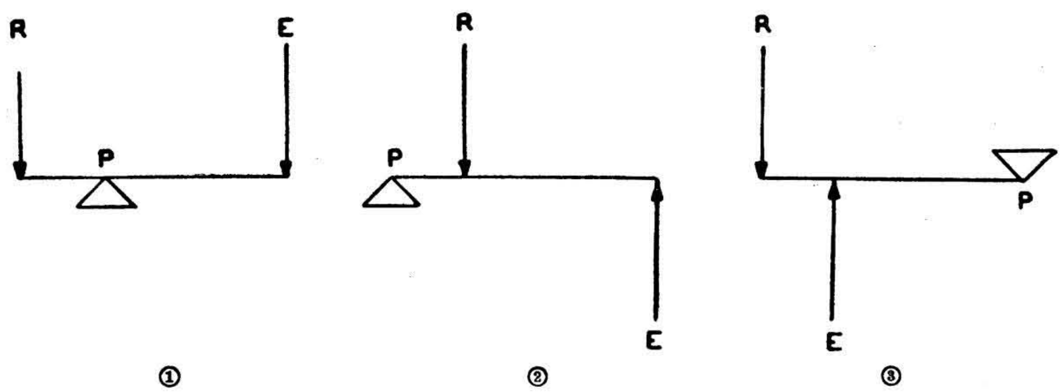


FIGURE 5.—Types of levers.

The product of a force and its lever arm is called the "moment" of that force.

Example: If, in figure 5②, the lever arm of the effort E is 8 inches, and the effort E equals 2 pounds, the moment of the effort E will be 16 inch-pounds. Likewise, if in figure 5②, the resistance R equals 8 pounds and its lever arm is 2 inches, the moment of the resistance R is 16 inch-pounds, and the lever is in balance.

d. General law of the lever.—From the foregoing examples, it can be seen that the general law of levers is as follows: *If a lever is in balance, the sum of the moments tending to turn the lever in one direction about an axis equals the sum of the moments tending to turn it in the opposite direction.* Thus, if several different efforts are applied to a lever, the sum of the moments of resistance will equal the sum of the moments of effort (if the lever is balanced).

e. Work done by levers.—Whenever a lever is used to do work, the work accomplished is always equal to the product of the resistance and the distance through which it is moved. Thus, if a weight of 10

pounds is lifted 2 feet by means of a lever, the work accomplished is 20 foot-pounds. Note that the work accomplished equals the sum of the moments of the resistance and also (ignoring friction) equals the sum of the moments of the effort expended.

f. Mechanical advantage.—As with pulleys, the mechanical advantage of a lever is equal to the sum of the resistance overcome divided by the sum of the efforts expended. Thus the mechanical advantage of the lever in figure 5① is 4. As with pulleys, the efficiency of a lever is always reduced by friction and often by other incidental forces tending to interfere with the functioning of the mechanism.

8. Gears.—*a. General.*—A gear is a wheel which has teeth designed to mesh with the teeth of a similar wheel, to which or from which motion may be transmitted. A set of gears is another device by which mechanical advantage can be gained. Gear systems are essentially systems of levers. They are used in many parts of an airplane—in the engine, in some pumps, etc.

b. Examples.—In figure 6①, assume that gear A receives clockwise motion from the drive shaft P. Gear B, with which gear A is meshed, is caused to turn in a counterclockwise direction. But since gear A has twice as many teeth as gear B, gear B will revolve twice for each revolution of gear A. In other words, by means of gear A, a mechanical advantage in speed of 2 (two revolutions of gear B per single revolution of the turning shaft) is gained. In this case, speed (in gear B) is gained at the expense of force (in the shaft to which gear B is attached).

(1) In figure 6②, gear B is turned by a shaft P, and gear A is turned by gear B. Gear A turns only one-half revolution per single revolution of the shaft, and the mechanical advantage in speed is 1/2. In this case, the force delivered by the shaft to which gear A is attached will be twice the force applied to shaft P, and the mechanical advantage in force will be 2. Thus force is gained at the expense of speed.

(2) Systems of gears of various sizes can be devised to perform many kinds of mechanical work. In the aircraft engine accessory section, for example, systems of gears connected to the crankshaft are used to drive the different accessories at different speeds.

9. Friction.—*a. General.*—Whenever one object is slid or rolled over another, irregularities in the contacting surfaces interlock and so cause a certain amount of resistance to the force exerted. This kind of resistance is known as "friction." Even the rubbing together of two pieces of ice would produce friction, though in this case the friction would be much less than in the rubbing together of two rough stones. Likewise, friction exists in the contact of air with all

parts of an airplane in flight. Friction is always present in machinery, and accounts partly for the fact that the work accomplished by a machine is never as much as the effort or energy exerted. Work done against friction is wasted. However, friction can be reduced by minimizing the necessary contacts of moving parts, by making contacting surfaces as smooth as possible, by the use of bearings, and by the use of lubricants.

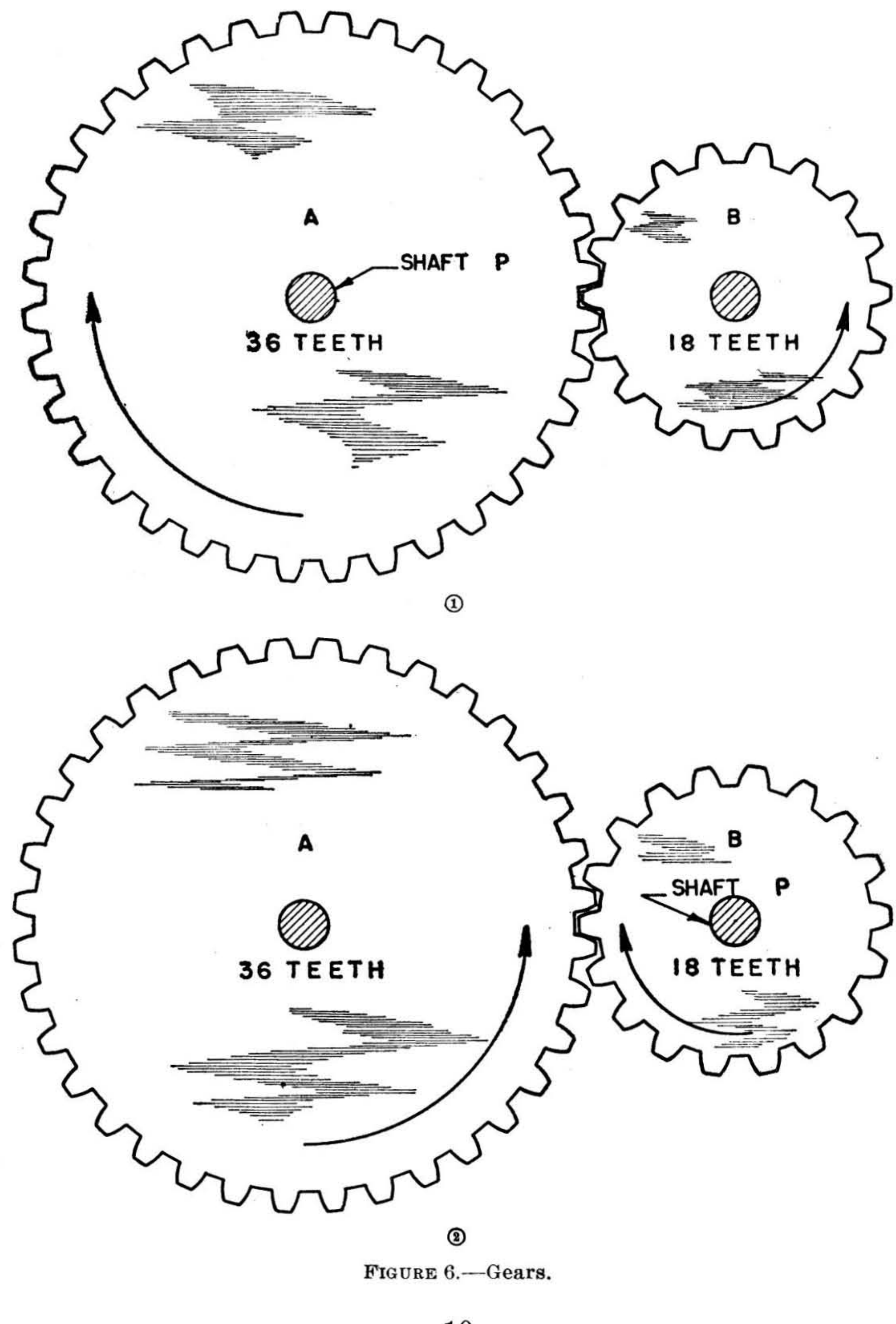
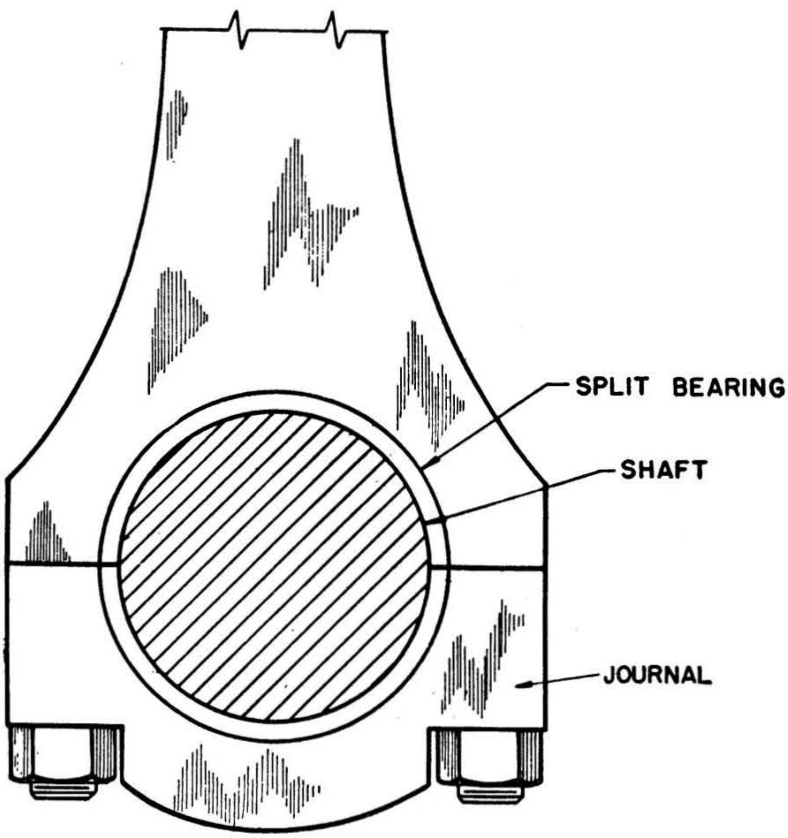


FIGURE 6.—Gears.

b. Kinds of friction.—There are two kinds of friction: sliding and rolling. Sliding friction is usually much greater than rolling friction. When one object is rolled over another the irregularities of the contacting surfaces obviously cause less resistance than if the two objects were rubbed against one another. Where practicable, devices are used in machinery to convert sliding friction into rolling friction.

c. Bearings.—To reduce the amount of work wasted in overcoming friction (and to reduce wear), devices called "bearings" are used where



① Common bearing.

FIGURE 7.—Bearings.

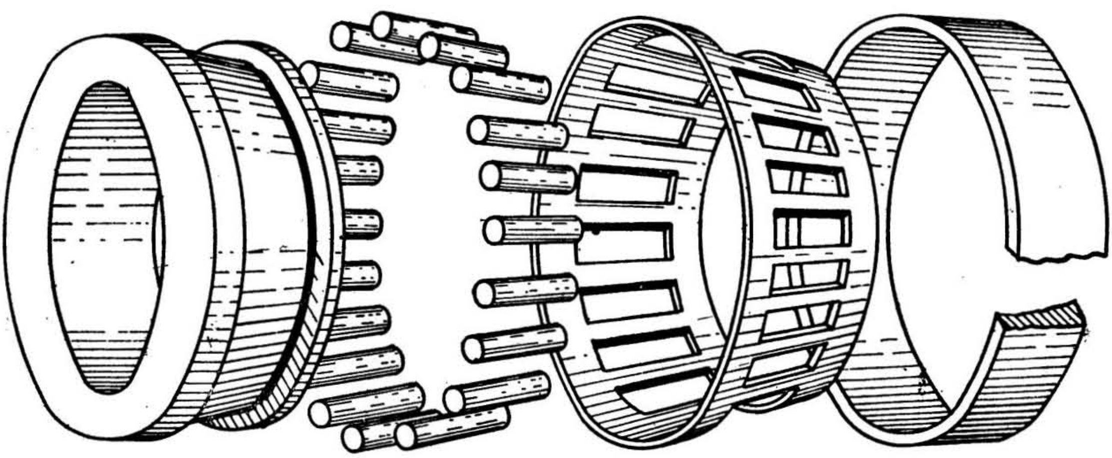
moving parts contact each other. Bearings are of three general types: common or friction, ball, and roller. The ball and roller types convert sliding friction into rolling friction. Oils, greases, and other lubricants are used to further reduce friction.

(1) In the common type bearing (fig. 7 ①), the shaft rotates in the journal. The journal is lined with some bearing metal such as babbitt, white metals, lead bronzes, etc., to reduce friction. Lubrication of this type of bearing supplies a film of oil between the shaft and bearing metal which further reduces friction.

(2) Roller bearings (fig. 7 ②) are used where heavy loads must be supported. A roller bearing consists of a cone (inner race), a set

of rollers, a cage, and a cup (outer race). The rollers, which are mounted between the inner and outer races, are held in place by the cage. They may be cylindrical or conical in shape. Rollers and races are made of very hard steel. The inner race is mounted on the shaft and turns with it. As the inner race is turned, the rollers rotate between the races and change sliding friction to rolling friction.

(3) Ball bearings are used where comparatively light loads are carried by the bearing. A ball bearing is similar in construction and operation to a roller bearing. Steel balls are used instead of rollers.



③ Tapered roller bearing—exploded view.
FIGURE 7.—Bearings.—Continued.

One or two rows of balls may be used. The inner race is mounted on the shaft and turns with it. As this race turns, the balls roll between it and the outer race. Thus practically all sliding friction is changed to rolling friction.

SECTION II

HEAT

10. General.—*a. Generation of heat.*—When a hole is being drilled in a piece of wood or metal, it is noticed that a certain amount of heat is generated; that is, the temperature of the drill and the object being drilled rises. Likewise, when a lead bullet strikes heavy armor plate,

so much heat is generated that the lead melts almost instantaneously. It is also noticed that when a gas is compressed (such as air being pumped into a tire), it is warmed. Finally, everyone has noted that when an object burns (unites with oxygen), considerable heat is given off. From these four examples it is apparent that heat can be generated in four ways: by friction, collision, compression, and chemical reaction.

b. Generation of heat in aircraft engines.—In an operating aircraft engine, heat is generated by sliding or rolling contact of moving parts (friction), by the action of pistons on the fuel-air mixture (compression), and by the combustion of gasoline (chemical reaction). Heat may also be produced by collision of some of the parts. The generation of this heat presents certain problems which the engine designer must solve if the engine is to operate efficiently.

11. Definition of heat.—Heat may be regarded as the energy of motion of the molecules (tiny particles) that make up an object. The energy of the molecules of any object can be increased by friction, collision, compression, or in some cases, chemical reaction. Their energy can be increased also by contact with, or nearness to, the molecules of a warmer object, that is, an object in which the molecules are moving faster. The ways in which heat is transferred from one object to another are explained in paragraph 16.

12. Measurement of heat.—*a. Definition of temperature.*—When an object is hot, it is said to have a "high temperature"; when it is cold, it is said to have a "low temperature." Temperature is the relative state of hotness or coldness of the object being discussed. Or, as already indicated, it is the relative energy of motion of the molecules that make up the object; the faster the motion of the molecules, the higher the temperature, and the slower the speed of the molecules, the lower the temperature.

b. Thermometers.—Most substances have a tendency to expand as they grow warmer and contract as they grow cooler. Temperature can therefore be easily measured by the expansion and contraction of any substance the volume of which changes proportionally within certain temperature limits. Any device containing such a substance and used to measure temperature is a thermometer. The substance most commonly used in liquid thermometers is mercury, since it is a liquid which changes proportionally in volume according to temperature changes and has a low freezing point (−39° C.) and a high boiling point (357° C.). When very low temperatures are to be measured, thermometers containing alcohol (freezing point −130° C.) instead of mercury are often used. Various other kinds of thermometers have been developed for special purposes—

(1) The vapor-pressure thermometer contains a highly volatile liquid which vaporizes or condenses (and thus exerts varying pressures on an indicator) according to changes in temperatures.

(2) In the resistance type of thermometer, the variations of the resistance of an electrical conductor indicate temperature changes.

(3) In the thermocouple thermometer, the registered difference between the electrical potentials of two different metals indicates temperature.

(4) In the bimetallic thermometer, temperature is indicated by the difference between the amounts of expansion of two metals.

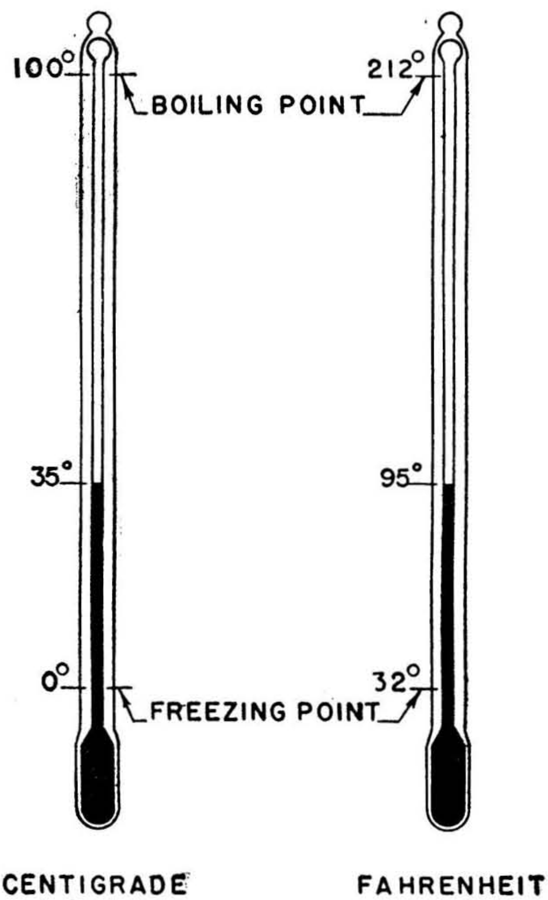


FIGURE 8.—Thermometers.

c. Centigrade and Fahrenheit scales.—(1) *Description.*—The two most commonly used scales for the graduation of thermometers are: centigrade (C.) and Fahrenheit (F.). On the centigrade scale the temperature of melting ice (freezing point) at sea level is marked "0°," and the temperature of boiling water (boiling point) at sea level, "100°." On the Fahrenheit scale the corresponding markings are "32°" and "212°." The centigrade scale is most used in connection with the metric system and in scientific work. Both scales are widely used in the United States. Figure 8, illustrating centigrade

and Fahrenheit thermometers side by side, shows their comparative readings.

(2) *Conversion.*—When it is desired to convert a reading on one scale into a reading on the other, the following simple formulas can be used:

$$C. = 5/9\ (F. - 32).$$
$$F. = (9/5)\ C. + 32.$$

Thus, to find the centigrade equivalent of 50° F.: $C. = 5/9\ (50 - 32) = 5/9\ (18) = 10°$. To find the Fahrenheit equivalent of −10° C.: $F. = 9/5\ (-10) + 32 = 14°$.

13. Units of heat.—For convenience, the standard unit of heat has been taken as the amount of heat required to raise the temperature of a unit quantity of water a given number of degrees according to a given temperature scale. The two most commonly used units of heat are the calorie and the British thermal unit (Btu). A calorie is the amount of heat required to raise the temperature of 1 gram of water 1° C. (centigrade). A Btu (252 calories) is the amount of heat required to raise the temperature of 1 pound of water 1° F. (Fahrenheit).

14. Mechanical equivalent of heat.—Whenever work is done, the *useful* work accomplished is never as much as the work expended. For instance, if the efficiency of a pulley system is 50 percent, this means that the work expended is twice as great as the useful work accomplished; that 50 percent of the effort is used to overcome friction. This wasted effort is converted into heat. Likewise, whenever work of any kind is done, either friction, collision, compression, or chemical reaction is involved and heat is generated. By experiment it has been proved that a calorie is equal to 427 gram-meters of work (a force of 427 grams exerted through a distance of 1 meter), and that a Btu is equal to 778 foot-pounds of work.

15. Heat conductivity.—At any given temperature, certain objects feel warmer than others. This difference is due to the difference between the heat conductivities of the substances involved. The heat conductivity of a substance is its ability to conduct or absorb heat. Most metals are good conductors of heat (and hence at room temperatures feel cool to the touch); gases are very poor conductors. Wood and liquids are poor conductors, and certain kinds of stone are good conductors. The heat conductivity of any substance depends on its molecular structure and on the state in which it occurs.

16. Transfer of heat.—*a. Types of heat transfer.*—Heat can be transferred within an object or from one object to another. Heat transfer by contact is known as "conduction." Heat transfer by proximity (nearness) occurs by a process known as "radiation." In

most cases of heat transfer, both of these processes are occurring, and *heat is transferred always from the warmer object to the cooler object*, never the reverse. A third process of heat transfer, involving the movement of a heated mass of gas or liquid from one place to another in a larger mass of gas or liquid, is called "convection."

b. Conduction.—Heat has already been described as the energy of motion of the molecules of an object. When the cooling liquid in an aircraft engine comes into contact with a hot cylinder wall, the molecules of the objects strike against one another and part of the high energy of motion in the molecules of the cylinder wall is transferred to the liquid. In this way the cylinder wall is cooled and the liquid is warmed. Similarly, the air rushing around an air-cooled engine during flight is warmed and the engine is cooled. Both of these examples illustrate the process of conduction.

c. Radiation.—If the hand is held at a distance from any very hot object, heat is felt, although the intervening air may be cold. In the same way the sun transmits heat to the earth without any intermediate medium above the earth's atmosphere. Such heat will pass through clear glass without warming it. When heat is transferred in this way it is said to be radiated. Thus an aircraft engine in operation is constantly transferring heat to its surroundings not only by conduction (by means of contact with the air and the coolant), but by radiation—a process in which objects at a distance are somewhat warmed but the intervening air is not appreciably warmed.

d. Convection.—Most substances expand when heated and thus become lighter per unit of volume. Water at the bottom of a kettle over a fire rises as it is heated, and the cooler water at the top of the kettle descends. Air passing over a hot stove likewise rises. In each case the heated fluid rises because it is lighter per unit of volume than the surrounding unheated fluid. Heat can therefore be transferred from one place to another by the tendency of a heated mass (of liquid or gas) to rise. This process is known as "convection." It is illustrated in the operation of airplane-cabin heating units, the heat from which is distributed to a considerable extent by convectional air currents. Currents of hot air rise and currents of cool air descend in directions determined by the locations of heater outlets and like factors.

17. Conditions of heat transfer.—*a. In conduction.*—The speed with which heat is transferred to or from one substance in contact with another substance depends on the heat conductivities, area of contact, and temperature differences of the substances involved. Heat will pass very slowly from a warm block of wood to a cool block of wood laid against it; it will pass rapidly from a warm block of metal

to a cool one laid against it. It will pass slowly from wood to metal or metal to wood, and still more slowly if only the corners (small areas) of the blocks touch. Obviously, the transfer of heat will be more rapid if the temperature difference between the blocks is great than if this difference is small.

b. In radiation.—Various substances radiate heat or absorb radiated heat with varying degrees of speed. As with conduction, the speed of radiation depends to some extent on the conductivities of the substances involved, on the areas exposed, and on the difference between their respective temperatures. To illustrate, metal radiates heat or absorbs radiated heat faster than wood; a rough surface radiates heat or absorbs radiated heat faster than a smooth surface (because roughness represents more area); and a hot object radiates heat faster to a cold object than a warm object would radiate it. Radiation also depends on the color of the surface involved. If a given substance has a dark surface, it will radiate more heat and absorb more radiated heat than if it has a light surface. This is true because a light surface tends to reflect heat. Thus a polished sheet of aluminum will radiate or absorb relatively less heat than a sheet with a dark-painted surface. Likewise, a heater with a dark case would radiate more heat than one with a light-colored case.

c. In convection.—The transfer of heat by convection depends on the speed of motion, the quantity, and the heat conductivity of the substance. Air-cooled engines are cooled not only by conduction (contact of air and oil with the hot engine) and radiation, but by convection (circulation of oil and the passage of air to, over, and from the engine). The more rapid the circulation of the air, the more rapid the cooling. Liquid-cooled engines similarly are cooled partly by convection (circulation of oil and the passage of the coolant through the cooling system). Again, the greater the quantity and the more rapid the circulation of the oil and the coolant, the more rapid the cooling effect. In an aircraft engine the design of the cooling system is based partly on the calculation of convectional factors involved. Likewise the design of any air heating system will involve calculations as to directions, speeds, and quantities of air to be circulated.

18. Changes of state.—*a. General.*—When a substance is changed to or from the form of solid, liquid, or vapor, it is said that a "change of state" takes place. The melting of ice and freezing of water, the evaporation of gasoline, the condensation of water vapor in the atmosphere, are all examples of change of state. In all changes of state, heat is involved, being absorbed or given off in certain quantities determined by the properties of the substances, temperatures and, in some cases, pressure conditions.

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b. Fusion.—Fusion or "melting" is the change of state from solid to liquid. The temperature at which any substance melts depends on its molecular structure; that is, on the amount of heat that must be applied to speed up the motion of its molecules to such an extent that the substance passes from the solid to the liquid state. Thus the melting point of ice is 32° F. (0° C.). The amount of heat required to change merely the state of a substance from solid to liquid without changing its actual temperature is the "heat of fusion." The heat of fusion of ice is 80 calories per gram, since 80 calories of heat are required to change a gram of ice at 32° F. to water at 32° F.

c. Solidification.—Solidification is the reverse of fusion. It is the change of state from a liquid to a solid. During this change from a liquid to a solid at the same temperature, the same amount of heat is given off as it takes to change the substance from a solid to a liquid.

d. Evaporation.—Evaporation is the change of state from liquid to vapor. When a liquid is evaporated in air, the particles of vapor occupy the space between the particles of air. At any given atmospheric temperature and pressure, there is only a certain amount of space in the air for vapor particles. When all this space is occupied, the air is said to be "saturated" and evaporation ceases. The amount of heat necessary to change one gram of a liquid to vapor at the same temperature is called the "heat of vaporization." Heat of vaporization, like heat of fusion, is different for different substances. The amount of heat necessary to change 1 gram of water at 100° C. to steam at 100° C. is 540 calories.

(1) One factor which affects the rate of evaporation is the temperature of the liquid being evaporated. If this temperature is high enough for evaporation to be accompanied by the formation of bubbles of vapor in the liquid, the liquid is said to be "boiling." This temperature is called the "boiling point" of the liquid. The boiling point, like the freezing point, is different for different liquids. The boiling point of a liquid is affected by pressure. For instance, pure water will boil at 212° F. (100° C.) at sea level, whereas it will boil at a much lower temperature at high altitudes. This fact is one of the determining factors in the choice of coolants for modern airplanes. Another factor in the choice of a liquid for use in cooling systems is the fact that the boiling point of a liquid may be raised or lowered by mixing it with another liquid.

(2) Evaporation has a strong cooling effect, because of the heat absorbed in the process. This cooling effect is partly responsible for the formation of ice on aircraft.

e. Condensation.—Condensation is the change of state from vapor to liquid. During this process the same amount of heat is given off as is

absorbed when change from a liquid to a vapor takes place. Thus, in condensing, a gram of water vapor at 100° C. gives off 540 calories of heat. The temperature at which water vapor in the atmosphere condenses is called the "dew point." Rain, snow, and other forms of precipitation are forms of condensed (or condensed and solidified) water vapor in the atmosphere.

f. Sublimation.—Sublimation is the change of state directly from solid to vapor. It also is affected by temperature and pressure. Solid carbon dioxide, which passes directly from the solid to the gaseous state, illustrates the process. Some substances that sublimate, such as iodine, can be converted back from vapor to solid directly. Carbon dioxide must first pass through the liquid state.

SECTION III

ELEMENTS OF FLUIDS

19. General.—A fluid is any substance made up of very small particles, or molecules, which have the ability to flow or move easily. This definition applies to both liquids and gases. Liquid and fluid are terms often used synonymously, but fluid has a much broader meaning. All liquids are fluids, but many fluids, such as air and other gases, are not liquids. Liquids and gases do not have the same distinguishing characteristics; nor do they follow the same rules of behavior. Since this is true, it is important to study the laws and principles applied to each.

20. Liquids.—The behavior of a liquid under various conditions is determined by its physical properties. Therefore, the physical properties determine the suitability of a liquid for some particular purpose. Among the most important physical properties of liquids are compressibility, thermal expansion, density, and specific gravity.

a. Compressibility.—When compressed, a fluid occupies a smaller space or volume than when not compressed. When compressed, it has a tendency to return to its original volume and therefore exerts an outward force in all directions. Certain substances, such as sponge rubber, offer little resistance to being pressed or squeezed into a smaller space. Other substances, such as iron, so strongly resist compression

that the reduction in volume is practically negligible. Liquids can be only slightly compressed; that is, the reduction of the volume which they occupy, even under extreme pressure, is very small. If a pressure of 100 pounds per square inch is applied to a body of water, the volume will decrease only three ten-thousandths of its original volume. Since other liquids behave in about the same way, liquids are usually considered incompressible.

b. Thermal expansion.—Liquids usually expand when heated. However, all liquids do not expand the same amount for a certain increase in temperature. If two flasks are placed in a heated vessel, and if one of these flasks is filled with water and the other with alcohol, it will be found that the alcohol expands much more than the water for the same rise of temperature. Kerosene and most oils expand more than water. Aircraft hydraulic systems, in which liquids are used, have provisions for compensating for this increase of volume in order to prevent breakage of the equipment.

c. Density.—The density of a substance is its weight per unit of volume. It may be expressed in pounds per cubic foot. The weight of water is 62.4 pounds per cubic foot. The weight of kerosene is only 50 pounds per cubic foot. Mercury, which weighs 849 pounds per cubic foot, has a much greater density than either kerosene or water. Iron has a density of 491 pounds per cubic foot. This is about eight times the density of water.

d. Specific gravity.—The specific gravity of a substance may be defined as the weight of a certain volume of the substance divided by the weight of an equal volume of water. The relation may be expressed as follows:

$$\text{Specific gravity} = \frac{\text{density of the substance}}{\text{density of water}}$$

Because it is plentiful, water has been chosen as a standard from which the specific gravities of other substances may be calculated. To simplify these calculations, the specific gravity of water has been set at unity, or 1. Specific gravities of other substances vary. Kerosene weighs 50 pounds per cubic foot, or eight-tenths the weight of water, and hence its specific gravity is 0.8; while mercury, which weighs 849 pounds per cubic foot, has a specific gravity of 13.5.

e. Measurement of specific gravity.—A body will sink until its weight is balanced by the weight of the liquid it displaces. Thus a piece of wood with a specific gravity of 0.7 will be submerged to seven-tenths of its volume when floating in water. This principle is used in the hydrometer, which consists of a large glass tube containing a weighted bulb. When a liquid is drawn into the lower

end of the tube, the bulb floats. If the density of the liquid is high, more of the bulb will project out of it than if the fluid were of low density. Since the weight of the bulb does not change, it can be graduated (marked with a scale), and the instrument can be used to compare the densities of liquids. Since the specific gravity of any liquid is determined by comparison of its density with that of water, the bulb is so graduated that it sinks to 1.000 in pure water, to values greater than 1.000 in liquids having densities less than water, and to values less than 1.000 in liquids having densities greater than water. Thus, the specific gravity of the electrolyte in a fully charged battery is found to be between 1.275 and 1.300. Any reading below this figure indicates that the battery is not completely charged.

21. Pressure production and transmission in liquids.—In discussing the production of pressure in liquids, it is necessary to deal with two distinct conditions—liquids at rest and liquids in motion. Certain reactions have been found to take place when pressure is applied to liquids at rest. These are commonly called "laws."

a. The most important of these laws is that confined liquids transmit pressure equally in all directions.

(1) If a jug or a bottle with a neck 1 square inch in cross-sectional area is filled with a liquid, and a force of 1 pound is exerted on a cork in the neck of the bottle, there will be a total force on the inner surface of the bottle equal to as many pounds as there are square inches of inner surface. Thus, if a force of 1 pound is exerted on the cork, and the area of the inner surface is equal to 50 square inches, there will be a force of 50 pounds exerted against the total inner surface. If the area of the inner surface is 150 square inches, the force will be 150 pounds, since the pressure is equally transmitted in all directions.

(2) By applications of this law, it is possible to produce tremendous forces in liquids by the use of pistons. The magnitude of these forces depends on the areas of the corresponding pistons. In figure 9, piston A has an area of ½ square inch at top and bottom. Piston B has an area of 10 square inches at top and bottom. The two are connected by a pipe the diameter of which is the same as that of piston A. When a 5-pound force is applied to the ½-square-inch piston, the produced pressure will be transmitted equally to an area of 10 square inches on the other piston. Since the surface of the large piston is 20 times that of the small piston, the 5-pound force is applied 20 times over that surface. This produces a force of 100 pounds. Of course, the same pressure is applied in all directions and is, therefore, equally transmitted over the other surfaces of the large cylinder. Where great pressures are involved, the piston walls must be built of such a material that they will resist the force produced by this pressure. In

figure 9, there has been a resultant force of 100 pounds produced from a 5-pound applied force.

b. Another law governing liquids at rest is that the pressure increases with the depth of the liquid. The total pressure on the bottom of a container filled with a liquid is equal to the weight of a column of that liquid which has the same bottom area as the bottom of the container and which is as high as the liquid is deep.

(1) For example, the total pressure on the bottom of a cylindrical container with a bottom area of 2 square feet and a height of 2 feet would be $2 \times 2 \times 62.4 = 249.6$ pounds (62.4 being the weight in pounds of 1 cubic foot of water). The pressure per square foot on the bottom would be one-half of 249.6 or 124.8 pounds and the pressure per square inch would be 124.8 divided by 144 or 0.86 pound (since 144 square inches equal 1 square foot).

(2) Assume that a can has several holes punched horizontally near the bottom and several other holes punched one above the other toward the top. When the can is filled with water, the flow from each hole at the bottom of the can will be the same, but the flow from the holes located one above the other will not be the same. The lower the hole, the stronger the flow, because of the greater weight of water, or pressure, above it. This example illustrates the fact that when no pressure is applied at the surface of a liquid, the pressure at any point in that liquid is dependent only on the depth and density of the liquid at that point (density being the weight of the liquid per unit of volume). The outward pressure against the walls of the container increases in direct proportion to the depth.

c. A combination of the laws given in *a* and *b* above brings about a useful and interesting result. If a small tube and a large tube, both filled with the same liquid, are connected to each other, the liquid will

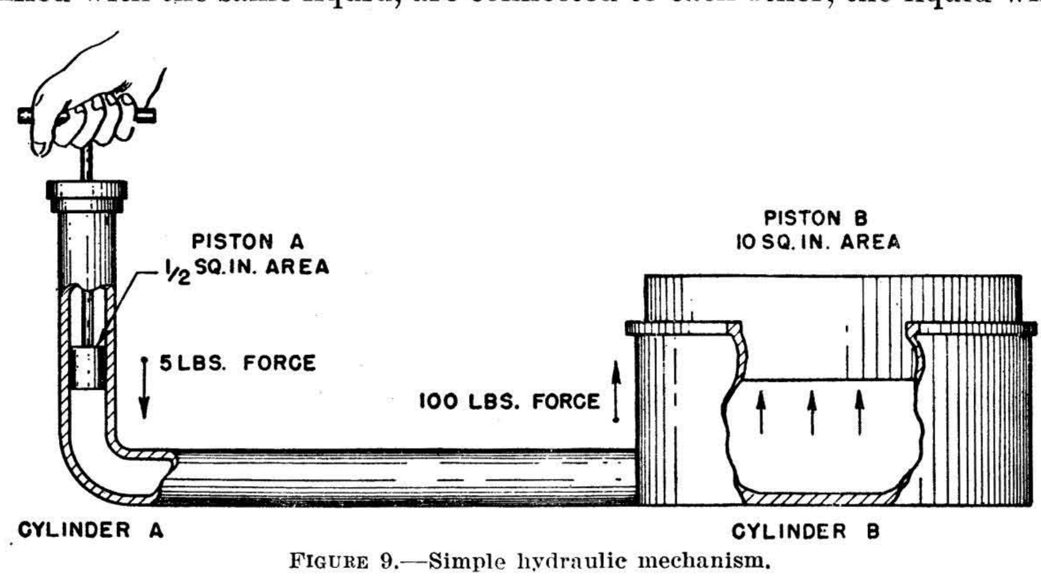


FIGURE 9.—Simple hydraulic mechanism.

remain at the same level in the small tube as in the large tube. Thus, water in the spout of a teakettle seeks the same height as the water in the kettle. For the same reason, the faucet of a water pipe connected to a standpipe of great height must be able to resist great pressure. If an ordinary wooden cask is filled with water and an upright steel pipe 1 square inch in cross-sectional area and 30 feet high, also filled with water, is connected to the sealed cask, the pressure on the inside surface of the cask will be very large, perhaps enough to burst the cask. The two laws of fluids at rest are in effect. The pressure at the lower end of the pipe is equal to the weight of 360 cubic inches of the liquid and is transmitted equally in all directions inside the cask, thus producing a total pressure the magnitude of which is dependent only on the height of the water in the pipe.

d. Most people have used the hydraulic jack, or applied the hydraulic automobile brake, with little thought of the principles by which they operate. A practical illustration of the hydraulic jack is shown in figure 9. A force of 50 pounds on the small piston the area of which is only ½ square inch will produce a force of 1,000 pounds on the larger piston, the area of which is 10 square inches. However, if a body weighing 1,000 pounds were to be raised by the large piston, the smaller piston would have to travel a distance of 10 inches to force the body up ½ inch, because the amount of liquid forced out by the small piston would be spread out over the large piston's surface of 10 square inches. Of course, when the small piston reached the bottom of the cylinder, the larger piston could not be moved higher. The apparatus shown in figure 9 would not be very useful, because a body could be raised only to a limited height. To make a more useful apparatus, a reservoir would have to be provided. to supply the hydraulic fluid to be pumped to the larger piston, and check valves would have to be provided to regulate the transfer of the fluid.

e. In figure 10, a more practical hydraulic system is shown. The

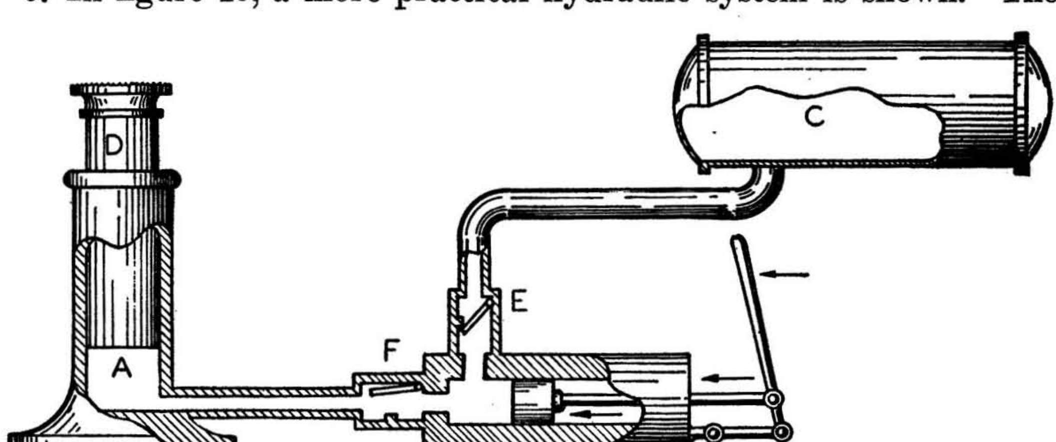


FIGURE 10.—Hydraulic jack.

hydraulic fluid is supplied from the reservoir C to the hand pump P, which forces the fluid into cylinder A. Valve F prevents the fluid that has been forced into the cylinder from returning, and valve E permits additional fluid to enter the pump and also prevents fluid which has entered the pump from being forced back into the reservoir. The pump can be operated until piston D has moved the desired height. The rate of movement of piston D will be determined by the rate at which the pump forces the fluid under it. The faster the fluid is forced into the cylinder, the faster the lifting rate will be. In aircraft, hydraulic systems are used for operating retractable landing gear, landing flaps, hydraulic brakes, and for many other mechanisms.

22. Gases.—*a. Definition.*—A gas is any substance in which the molecules (very small particles of which it is composed) are separated by relatively large spaces. We live at the bottom of an ocean of air which is a mixture of gases—mostly nitrogen, oxygen, carbon dioxide, and small amounts of other gases, including some water vapor. The principal difference between liquids and gases is that while liquids are almost incompressible, gases are very compressible because of the large spaces between the molecules.

b. Compressibility.—Gases not only are very compressible, but they expand much more than liquids when heat is applied. Although air is not ordinarily considered as a gas, it is a gas to which the gas laws may be applied. Since the particles of a gas are widely separated, even a slight pressure upon a confined gas will cause the particles to come closer together. Figure 11 is a simple illustration of the compressibility and elastic qualities of a gas.

c. Pressure-volume relation at constant temperature.—In figure 11, the pressure in a 12-inch cylinder with an airtight-fitting piston is 15 pounds per square inch. Suppose the piston is pushed down so that the gas is compressed into only 6 inches of the cylinder. None of the gas is lost in this process, but it is occupying only one-half the volume it occupied before. Hence the pressure on the inside of the cylinder is increased to 30 pounds per square inch, or just double the original pressure. Suppose that still more force is exerted on the piston, and the gas is compressed into 4 inches of the cylinder. The pressure of the gas on the inside becomes 45 pounds per square inch or three times as great as it was in the beginning, and the volume has decreased to one-third the original volume. In conclusion, it can be stated that the volume a gas occupies is in inverse proportion to the pressure exerted upon the gas, if the temperature remains constant.

d. Volume-temperature relationship at constant pressure.—In discussing figure 11, it was assumed that there was no change in the temperature of the gas. Actually, the volume of a given quantity of gas

and pressure on it are strongly affected by temperature changes. The lower the temperature of a given quantity of gas at a constant pressure, the smaller the space it will occupy. A gas will expand when heat is applied, as is obvious when a rubber balloon is placed over a heated stove. The gas or air inside the balloon will expand as its temperature is increased. In figure 12, notice that as the tempera-

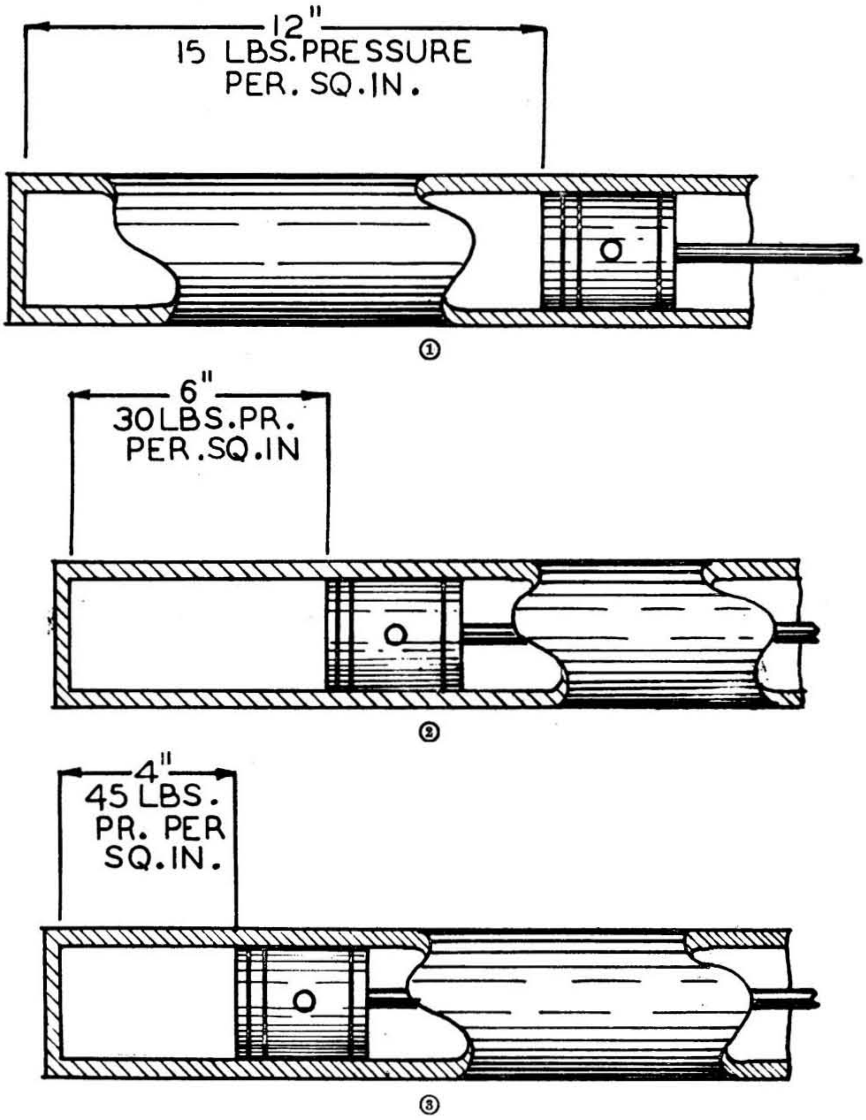


FIGURE 11.—Pressure-volume relationship of gases.

ture of the gas increases, the volume of the gas increases likewise. As the gas expands it pushes the piston back, until the pressure of the gas equals the pressure exerted by the piston. In this way the pressure inside the cylinder is kept constant at 15 pounds per square inch. In figure 12 ①, the gas takes up a space of 12 inches of the cylinder and has a pressure of 15 pounds per square inch at the prevailing temperature. As the temperature of the gas is increased

(fig. 12 ②) the piston moves back in the cylinder to compensate for an increase in volume of the gas. If the temperature is further increased, the volume will likewise increase (fig. 12 ③). It may be stated, therefore, that the volume of a gas will increase in direct proportion to the absolute temperature if the pressure remains the same.

e. Pressure-temperature relationship at constant volume.—Suppose that in figure 12 ② the piston had not been allowed to move back. The volume would tend to increase, but could not do so. Therefore, the pressure on the inside of the cylinder would increase. A further

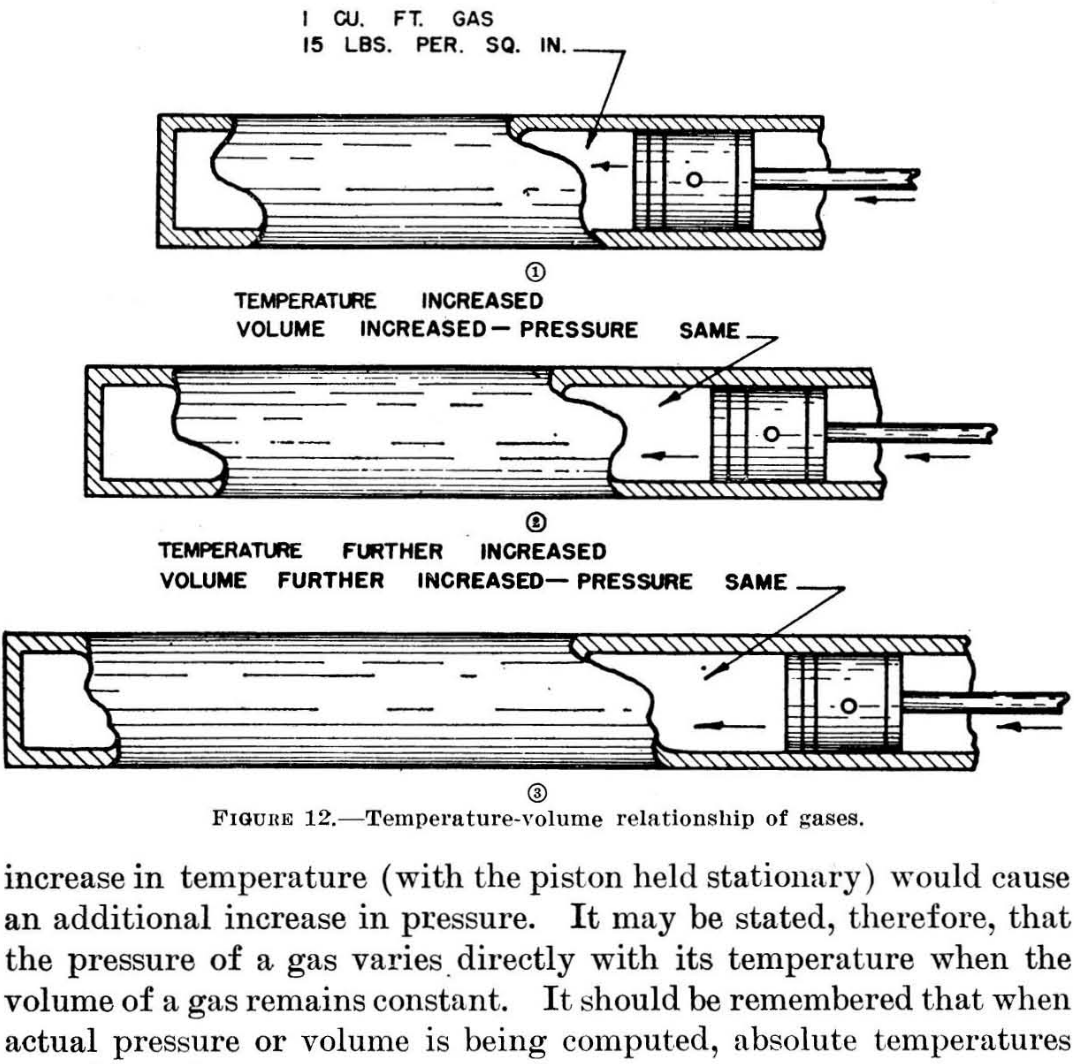


FIGURE 12.—Temperature-volume relationship of gases.

increase in temperature (with the piston held stationary) would cause an additional increase in pressure. It may be stated, therefore, that the pressure of a gas varies directly with its temperature when the volume of a gas remains constant. It should be remembered that when actual pressure or volume is being computed, absolute temperatures must be used.

23. Pressure production and transmission in gases.—The laws which govern pressure transmission in gases are essentially the same as those governing liquids. However, pressure transmission in gases will not take immediate effect. In figure 13, a great pressure can be produced by the piston in the cylinder of the pump as the

piston is suddenly moved downward. However, since gases are compressible, the pressure produced in the storage tank will not be equal to the pressure produced in the pump. Thus, if the pressure in the storage tank is 30 pounds per square inch, the pressure in the cylinder of the pump must be a little more than 30 pounds per square inch in order to force the gas into the tank. Suppose that when the piston is suddenly pushed down in the pump, a pressure of 35 pounds per square inch is applied to the valve D. This does not mean that there is a pressure of 35 pounds per square inch built up on the inside of the pressure tank; it will take several strokes of the piston to build the pressure inside the tank to 35 pounds per square inch. When a pressure of 35 pounds per square inch inside the tank is reached, it is necessary to apply a still greater pressure to the valve to force additional air into the tank. However, the pressure in the tank will be transmitted equally in all directions inside the tank.

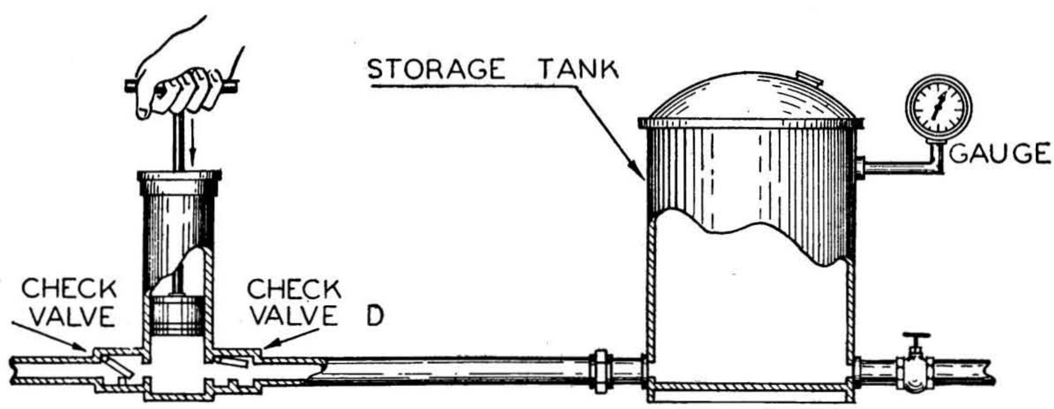


FIGURE 13.—Simple air pressure system.

24. Changes of state.—It is possible to increase the pressure of gas inside a storage tank to such an extent that the gas particles will be so compact that the gas becomes liquid. When this limit is reached, no more gas can be compressed into the storage tank, since liquids are practically incompressible. Great quantities of gas can be stored in a few cubic feet of space under such high pressure. The greater the pressure in the tank, the more dense the gas becomes. Only a few of the gases used in aircraft are compressed into a liquid state. In a carbon-dioxide cylinder, approximately three-fourths of the gas is changed into a liquid state, the remainder existing in a gaseous form in the upper part of the cylinder. When the cylinder valve is opened, the pressure of the gas forces the liquid out. As the liquid leaves the cylinder, the pressure decreases and the liquid changes to a gas.

25. Atmosphere.—*a. Definition and description.*—The atmosphere is the envelope of air surrounding the earth. This envelope of air extends to about 200 miles above the surface of the earth and is

deeper at the Equator than at the poles. The atmosphere is divided into two parts—the troposphere, or atmosphere below 36,000 feet, and the stratosphere, or upper portion of the atmosphere. The troposphere contains about three-fourths (by weight) of the total atmosphere. In the stratosphere, which consists of thinner air, the temperature is constant and only horizontal air currents occur, because of the rotation of the earth.

b. Composition.—Air is a mixture of gases, ordinarily consisting of approximately 21 parts oxygen and 78 parts nitrogen, plus very small parts of other gases, primarily water vapor and carbon dioxide. There is no chemical union between these gases, and the composition of air in open places remains almost constant.

c. Weight.—The weight of the gases which compose the atmosphere exerts a pressure against the surface of the earth. Thus, any area on the earth supports the weight of a column of air which extends above it for a distance of 200 miles, or the depth of the atmosphere. By direct measurement it has been found that an area of 1 square inch at sea level supports a vertical column of air that weighs 14.7 pounds. At higher altitudes this force is less because the column of air supported is shorter. Therefore, the pressure exerted by the weight of the atmosphere on any area grows correspondingly smaller with any increase in altitude above sea level, because of the lessened weight of the column of air that rises vertically above it.

d. Measurement of atmospheric pressure.—(1) Since air has weight, it exerts force against any surface immersed in it. A method of measuring atmospheric pressure is illustrated in figure 14. A tube nearly 3 feet long and closed at one end is filled with mercury. A dish is half filled with mercury. The open end of the tube is closed with the finger to prevent the escape of mercury, and the tube is inverted and placed with its open end below the surface of the mercury in the dish. Then the finger is withdrawn. The mercury in the tube sinks until it stands at a height of about 30 inches above the mercury level in the dish. Thus the pressure of the atmosphere on the mercury in the dish supports the column of mercury in the tube. If the procedure is performed at sea level, it will be found that the atmosphere, because of its weight, will support a column of mercury approximately 30 inches high. This is equivalent to a pressure of 14.7 pounds per square inch.

(2) If this tube of mercury with the dish is carried to a higher elevation, the level of the mercury in the tube will drop, because air pressure at higher altitudes is less than at lower altitudes.

(3) Instruments for the measurement of atmospheric pressure are known as "barometers." A tube of mercury or any other liquid is one

kind of barometer. Those in most common use employ an aneroid or pressure-sensitive capsule.

e. Variations of atmospheric pressure.—Air pressure is not constant, but the average daily variation in any locality is usually small. However, local conditions may cause relatively large variations over a larger area.

(1) Six factors may influence the condition of the atmosphere at any time or place: temperature, pressure, humidity, wind, clouds, and precipitation. The height of the mercury column of a barometer may

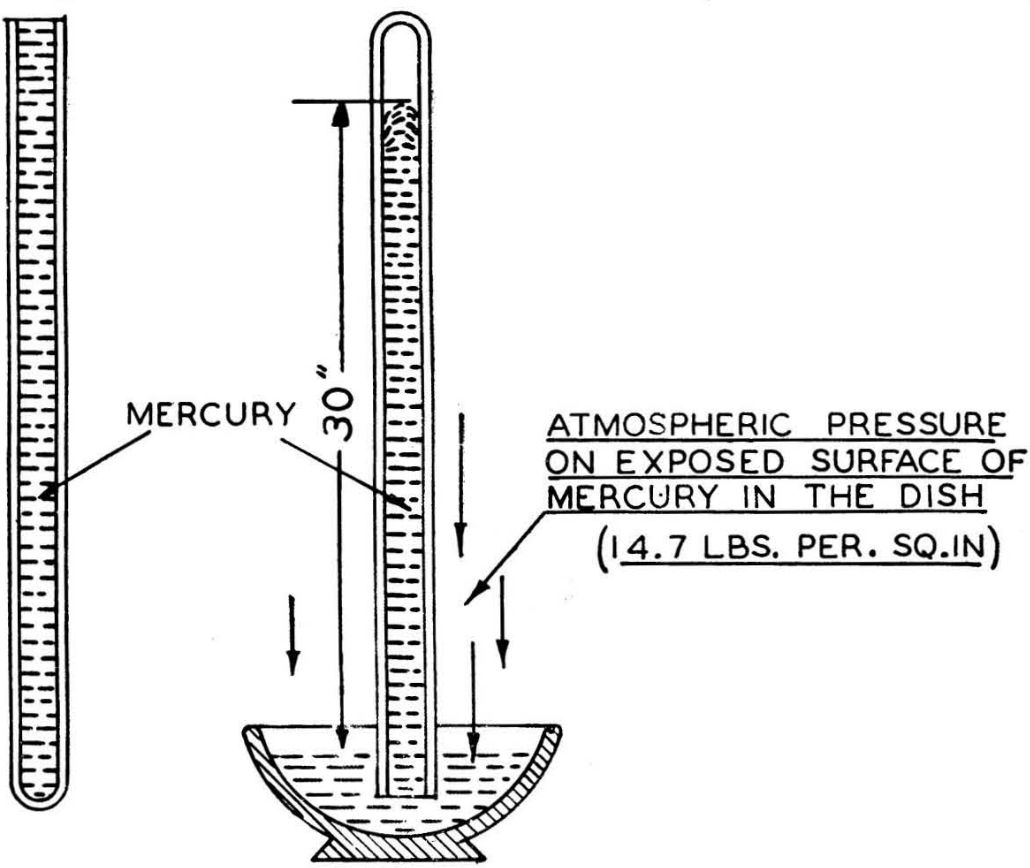


FIGURE 14.—Measurement of atmospheric pressure.

vary considerably in localities at the same elevation, the reason being that disturbances in the atmosphere affect the pressure at the earth's surface.

(2) It has been found that a low or rapidly falling atmospheric pressure is usually accompanied, or soon followed, by stormy conditions. Hence the barometer is of considerable importance in forecasting weather conditions some hours ahead, although weather forecasts are based only in part upon barometric readings.

f. Dew point and humidity.—(1) *Dew point.*—The temperature to which the atmosphere must be cooled in order that the water vapor within it may begin to condense is called the "dew point." At night

certain objects may lose heat more rapidly than others, and warm moist air may come in contact with them; then water vapor in the air is condensed and deposited on these objects. This moisture is dew. The dew point depends on the temperature, pressure, and humidity of the atmosphere.

(2) *Humidity*.—Humidity may be defined as the amount of water vapor present in the air at any one time. There is less than one-third of 1 percent (0.003) water vapor in the whole atmosphere, but conditions of pressure and temperature of the air at various places on the earth's surface may cause the air to contain as much water vapor as possible without its being precipitated. When such a condition occurs, the air is said to be "saturated." "Relative humidity" is the comparison of the amount of water vapor present in the air with the amount that would be present if the air were completely saturated, temperature and pressure remaining constant. If, at a given time, the air is only half saturated, the relative humidity would be 50 percent. Since humidity affects the occurrence of rain, snow, clouds, frost, etc., records of humidity are kept carefully for aeronautical purposes.

SECTION IV

ELEMENTARY AERODYNAMICS

26. General.—*a. Resistance of air.*—The flight of an airplane depends on the fact that air has weight and substance, and therefore tends to resist the passage of any object through it. The manner in which an airplane is held up in the air (against the force of gravity) and is steered can be made clear by the use of simple illustrations.

(1) If a flat piece of cardboard is pulled rapidly through the air, flat side up and edge foremost, little air resistance is noticed. That is, the air particles are easily separated by the sharp edge. Now, if the leading (forward) edge of the cardboard is tilted upward slightly, more air resistance will be noticed when the cardboard is moved (because a greater area of cardboard opposes the air) and the cardboard will tend to rise as it moves forward. If the leading edge is now tilted downward, the cardboard will tend to move down-

ward as it moves forward. Finally, if the cardboard is held vertically and edge foremost, with the leading edge turned slightly sideward, when pulled forward the cardboard will tend to move sideward as well as forward.

(2) The reason for the deflection (upward or downward or sideward movement) of the cardboard when tilted slightly is a difference in the air resistance produced on opposite sides of the cardboard when it is moved. When it is tilted upward, greater air resistance is produced on the under side because this is the side opposing the air. On this side the air becomes denser (the particles move closer together) when the cardboard is moved against it; hence it exerts more resistance or pressure on the cardboard. Since the air pressure is now greater on the under side than on the upper side (which is not opposed to the air), the cardboard rises somewhat as it moves forward. The same thing happens when the cardboard, held vertically with a slight sideward turn, moves sideward. In both cases, there is a difference between the air pressures on the two sides, with the greater pressure pushing the cardboard in the direction of the smaller pressure.

b. Principles of flight.—The flight of an airplane depends on such a difference between air pressures. The blades of the propeller are so designed that when they rotate, their shape and position cause a higher air pressure to be built up behind them than in front of them; hence the airplane is pulled forward. This forward force is called "thrust." The wings are so designed that they convert part of the air resistance into an upward force, or "lift," which keeps the airplane in the air against the force of gravity. The control surfaces—ailerons, rudder, and elevators—are so designed that when they are tilted in certain ways, the course of the airplane is changed accord-airfoil.

27. Airfoils and airfoil sections.—Any part of an airplane that converts air resistance into a force useful for flight is called an "airfoil." The propeller blades, wings, stabilizers, and control surfaces are all airfoils. An "airfoil section" is a cross section of an airfoil.

28. Aerodynamic principle of airfoil.—*a. Lift.*—Figure 15 shows the airfoil section of a wing, with air flowing over the upper and lower surfaces. The upper surface of the wing has a curved surface. It will be noticed that the lines representing the flow of air are farther apart over the upper surface than they are under the bottom surface of the section. Where the lines are widely spaced, the density of the air is less than where they are more closely spaced.

This difference between the air densities is due to the fact that the impact of the air particles on the curved surface tends to separate them more than they are separated below the wing. Since air exerts pressure in proportion to its density, the pressure on the under side of the airfoil is greater than on the curved side. The difference between these two pressures results in a force (lift) exterted upward against

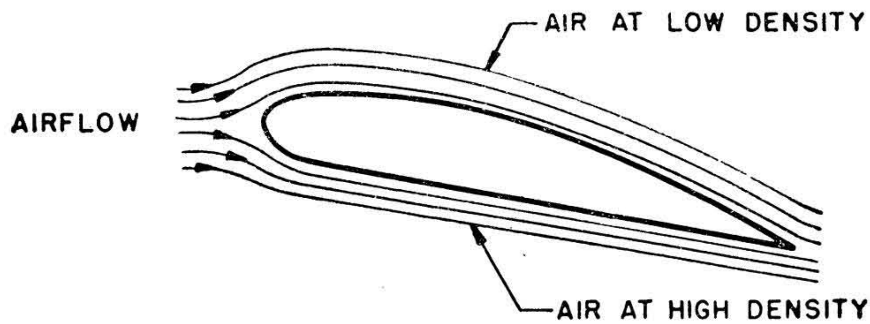


FIGURE 15.—Airfoil section showing air flow.

the section. It is this upward force against the wings that keeps an airplane aloft despite the downward pull of gravity. A similarly caused difference in pressures on the control surfaces of an airplane changes the attitude of the airplane.

b. Drag.—Not all the air resistance encountered by the airfoil is converted into lift. Some of the resistance remains to hinder forward motion. Figure 16 shows how the air, broken into two streams, produces both lift and drag.

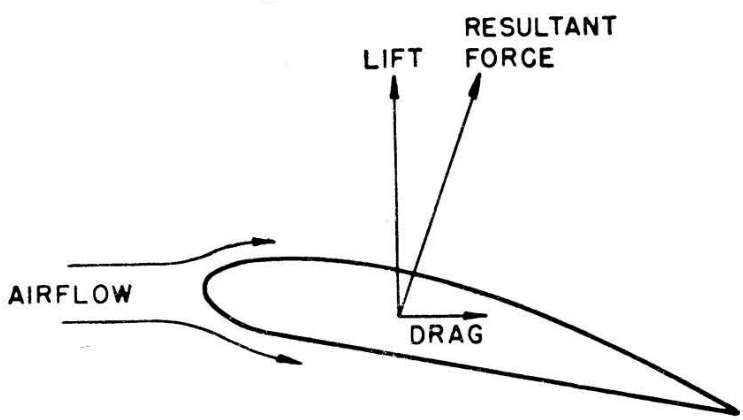


FIGURE 16.—Airfoil section showing production of lift and drag.

c. Factors governing lift and drag.—The design of an airfoil for maximum efficiency is a complex and difficult problem. Lift and drag, the two forces into which air resistance is converted, depend on the following factors:

(1) *Angle of attack.*—Up to a certain limit, the greater the angle of attack (the tilt above or below the horizontal) of an airfoil, the greater the lift produced. Drag also increases when the angle of attack

is increased, because of the larger area of the airfoil opposing the air. Beyond a certain angle, called the "critical angle of attack," lift increases little and then begins to decrease, while drag continues to increase rapidly up to an angle of 90°. The reason for the decrease in lift and increase in drag at angles greater than the critical angle is turbulence of the air around the airfoil. Turbulence is the existence of eddies of air which break up the pattern of the airflow on the upper surface of the wing. This increases the density of the air on top of the airfoil and thus decreases the effective upward force and increases the friction between the airfoil and the air. A condition of turbulence is shown in figure 17.

(2) *Velocity.*—The velocity with which air flows over the airfoil also affects lift and drag. The greater the velocity, the greater the lift and drag tend to be.

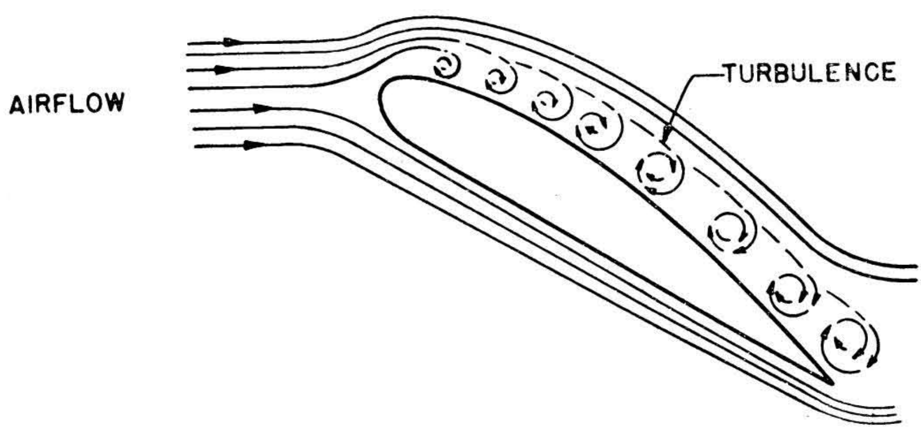


FIGURE 17.—Airfoil section showing turbulence.

(3) *Area.*—The lift developed by an airfoil is determined also by its area. The larger the area, the greater the lift.

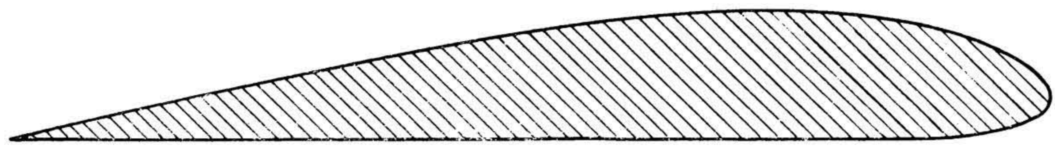
(4) *Shape.*—The shape of the airfoil surface also affects lift and drag. Ordinarily, square edges tend to cause increased drag. The angles of the leading and trailing edges to the direction of the airflow are also important factors.

(5) *Smoothness of surface.*—An airfoil with a smooth surface develops more lift in relation to drag than an airfoil with a rough surface. A rough surface tends to produce turbulence, which, as has been seen, reduces lift and increases drag. The importance of a smooth surface accounts for the great care given to the polishing of surfaces on an airplane.

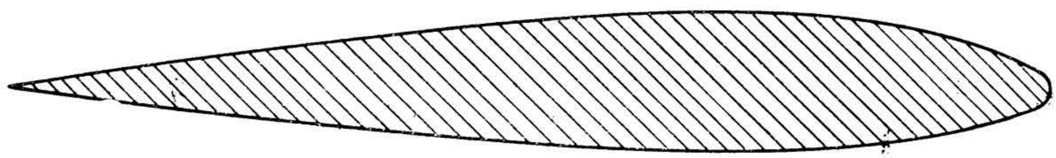
(6) *Altitude.*—The envelope of air surrounding the earth becomes rapidly thinner with increasing altitude. The velocity of the airflow over the wings (that is, the speed of the airplane) or the area of the airfoils, or both, must therefore be relatively greater at higher alti-

tudes to produce the necessary lift, since the pull of gravity remains practically the same as at lower altitudes.

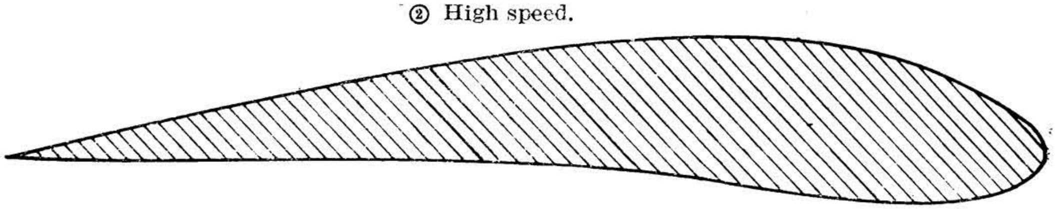
29. Wings.—The wings are those parts of the airplane which, by developing lift, keep it in the air against the pull of gravity. Each different type of airplane demands a particular type of airfoil, depending upon the weight of the plane, operating speeds, loads to be carried, necessary maneuvers to be executed, altitudes to be reached, climbing speed desired, and other factors. The design of the wing is, in short, a part of the design of the whole airplane, and must be consistent with that design. Figure 18 shows airfoil sections of several types of wings.



① General purpose.



② High speed.



③ High lift.

FIGURE 18.—Typical wing sections.

30. Control surfaces.—*a. Ailerons.*—The ailerons, which are approximately rectangular, movable surfaces located horizontally on the trailing (rear) edges of the wings (fig. 19) and on the lower wings in biplanes, give the pilot lateral control of the airplane. When manipulated, they cause the airplane to roll to either side, or to recover from a rolling motion. These airfoils are adjusted so that when one is tilted downward the other is tilted upward, causing one wing to rise and the other to descend. They operate on the same airflow principle as the wing. The aileron which is tilted downward from the wing causes this wing to rise, while the airflow over the upward-tilted aileron is such that its wing is caused to descend. Like wings, ailerons are designed according to the needs of the particular airplane.

b. Elevators.—The elevators (fig. 19) which are movable airfoil surfaces at the tail of the airplane, move upward and downward together, and give the pilot vertical (upward and downward) control.

When the rear edges of the elevators are turned downward, the airflow causes the nose of the airplane to move downward; when the rear edges are turned upward, the nose of the airplane moves upward. Elevators, like wings and ailerons, are designed differently for different types of airplanes.

c. Rudder.—The rudder (fig. 19), is another airfoil which is located at the tail. It gives the pilot lateral (left and right) control of the airplane. When its rear edge is to the left, the moving airplane moves toward the left; when the rear edge is to the right, the airplane moves toward the right. Thus the rudder completes the control surfaces which the pilot needs in order to manage the airplane in all attitudes, or positions, of flight.

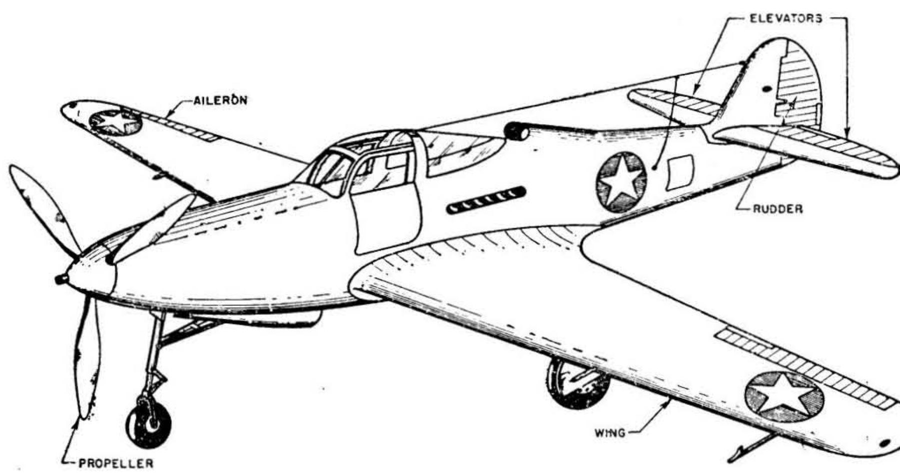


FIGURE 19.—Control surfaces of an airplane.

31. Propeller.—*a. Purpose.*—The propeller operates as an airfoil in a somewhat different manner from the wings and control surfaces. While the wings provide lift and the control surfaces determine direction, the propeller, turned by the propeller shaft from the engine, pulls the airplane forward.

b. Principle of operation.—The propeller blades are constructed with a slight twist. As they rotate (fig. 20) their leading (forward) edges "bite" into the air, causing high air pressure to be built up on their rearward sides, which are the sides opposing the air. This pressure is exerted partly forward (corresponding to lift) and hence the blades pull the airplane forward. The problem of avoiding too high pressure toward the ends of the blades, because of the more rapid rotation of these parts, is solved by tapering the blades. The taper also serves to minimize turbulence.

c. Angle of attack.—Like the wing, the propeller functions satisfactorily (develops a good pulling force) if the angle of attack is not too large. Too large an angle results in increased drag, increased tur-

bulence, and decreased thrust, besides strain on the engine. Since the most efficient angle of attack of the blades will depend on whether the airplane is climbing, descending, or level, propellers have been developed with controllable blades. The blades of these propellers can be set at the desired angle by means of controls located in the cockpit. Large angles of attack are used in descent, slight angles in climbing, and intermediate angles in level flight. This control of the blades results in more efficient use of the power developed by the engine.

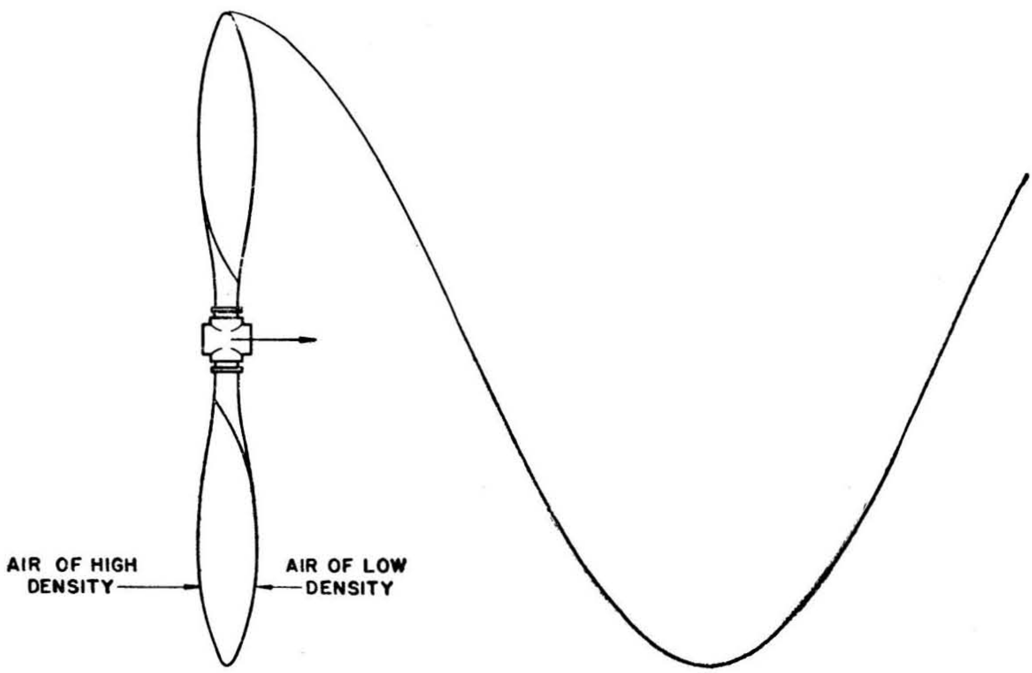


FIGURE 20.—Propeller, showing thrust development.

32. Parasite resistance.—The only parts of an airplane designed to convert air resistance into useful force are the wings, stabilizers, control surfaces, and propeller. All other parts of the airplane tend to retard its flight because of the resistance of the air to their passage. This kind of retarding force is called "parasite resistance" (parasite drag). In order to reduce it to a minimum, the airplane designer includes as many parts as possible within the main structure of the airplane, and streamlines this structure. Parts which must necessarily be outside or partly outside the structure, such as gun turrets, are likewise streamlined in a manner consistent with the streamlining of the whole structure. All surfaces are kept as smooth as possible to avoid the creation of tiny eddies of air that would produce extra drag. Every pound of resistance avoided is a pound of force gained to push the airplane forward.

33. Stability.—It is obvious that during flight the various parts of an airplane produce air currents in many directions, in addition to

already existing currents. These currents affect the flight of the airplane to some extent. An airplane must be constructed as a whole, therefore, in such a fashion that the air currents existing about it when it is in flight do not make it difficult to keep under control. An airplane so constructed is said to have satisfactory "stability," or tendency to recover from momentary deviations from normal flight.

Section V

PRINCIPLES OF ELECTRICITY

34. General.—*a. Uses and advantages.*—In modern aircraft, the chief interest in electricity lies, first, in the means of transmitting it; second, in the ways in which it is used to produce active forces; and third, in the many convenient ways of producing it. Electrical power generated by chemical cells, generators, and magnetos is easily and quickly delivered by conductors to any point where it is transformed into heat, light, or mechanical work.

b. Nature of electricity.—The exact nature of electricity is unknown. However, its effects, the laws governing its action, and the methods of measuring, controlling, and using it are well understood.

(1) All matter is thought to be composed of positive and negative charges of electricity. A body is in a stable or neutral state when the charges of positive and negative electricity in that body are equal. When a body is neutral, it is said to have normal or zero potential. Likewise, should a body become positively charged, it holds an excess of positive electricity and the potential is above normal. Since it is the tendency for all bodies carrying an electrical charge to become neutral, the earth may be considered as an ocean of electricity in that it is the level toward which all electricity flows, in the same way that all water flows to the level of the ocean. Any electrically charged body put into communication with the earth, will, in time, be reduced to the standard or zero potential of the earth, just as water anywhere on earth will eventually find its way to sea level.

(2) Since the zero of potential is arbitrarily taken as that of the earth, bodies can be made to bear not only opposite charges of electricity toward each other, but also positive or negative charges in relation to the earth. One body cannot be charged with a quantity of positive electricity without an equal charge of negative electricity being established somewhere else, or vice versa. Because the sum of all equal positive and negative quantities is zero, the sum of all electrical charges in the universe is zero.

c. Forms of electricity.—Electricity, according to the nature of its effect, is found in three forms: static, dynamic, and electromagnetic wave. All these are of importance in aircraft.

(1) *Static electricity.*—Static electricity is the result of charges being held upon bodies and discharged intermittently. These charges may be generated by friction between certain materials; for example, glass and silk. The electricity thus produced normally remains at rest, but it will readily dissipate its energy when allowed to discharge to some other body or to the ground. The discharge of static electricity can be illustrated by bringing a finger close to a rapidly moving leather belt running over a pulley. A momentary spark of considerable intensity will jump from the belt to the finger. The static charges which accumulate on a vehicle must be considered when one is filling a gasoline tank or hauling gasoline. The nozzle on a gasoline hose should be in contact with the filler opening on a vehicle before gasoline is pumped into the tank in order to ground the accumulated static charges. A chain dragging from a gasoline truck permits charges accumulated by the truck to pass safely to the ground without sparking. Sparks from such accumulated charges have resulted in disastrous accidents.

(2) *Dynamic electricity.*—Dynamic electricity is the result of charges continuously supplied and discharged. It is electricity in motion, or current electricity, and is generated by chemical cells, generators, and magnetos. It is capable of doing work and is used in the operation of aircraft electrical equipment, such as the starting motor, lights, etc.

(3) *Electromagnetic wave.*—Electricity in this form is the basis of radio transmission and reception.

35. Electrical circuit.—*a. Definition.*—A system of wires or conductors over which an electrical current can be made to flow is called a circuit. The simplest circuit consists of a continuous conducting path through a resistance from the positive terminal to the negative terminal of the source of electricity. In practice, this circuit may be made of wires connecting a battery with lamps, motors, heaters, etc.

b. Flow of electricity.—The action of electricity is quite similar

to the flow of liquids. Water flows under pressure due to a difference in water level. Electricity flows through a conductor under the influence of electromotive force due to a "difference of potential" between the two ends of the conductor. Potential is the same as electrical level, and difference of potential is a difference in electrical level.

36. Hydraulic analogy.—*a. Electromotive force.*—As has been stated, dynamic electricity flows in a stream or current similar to the flow of water. An electric current flowing along a wire may be compared to water flowing through a pipe. Water flows through a pipe if there is a difference in pressure between the two ends, as in figure 21①. In this case the difference in pressure is caused by a difference in level between A and B. In the same manner, electric current will flow through a wire if there is a difference in potential (electrical

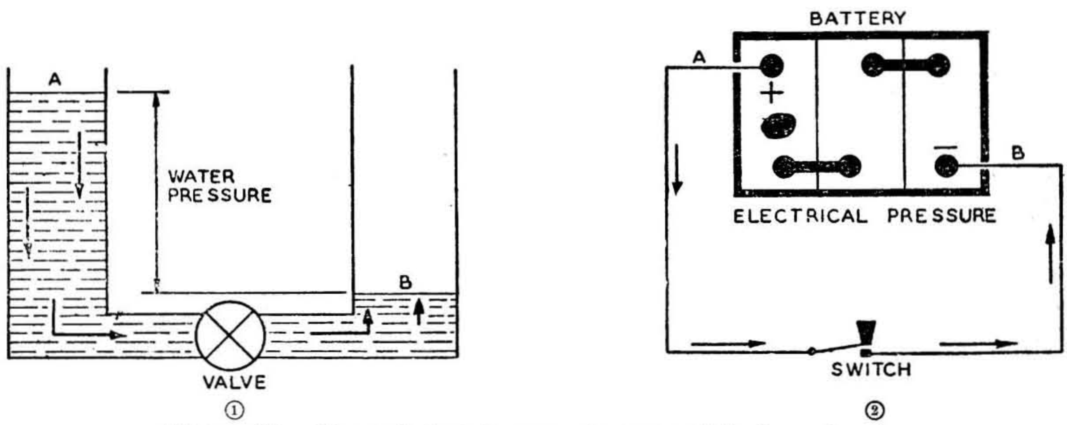


FIGURE 21.—Flow of electric current compared to flow of water.

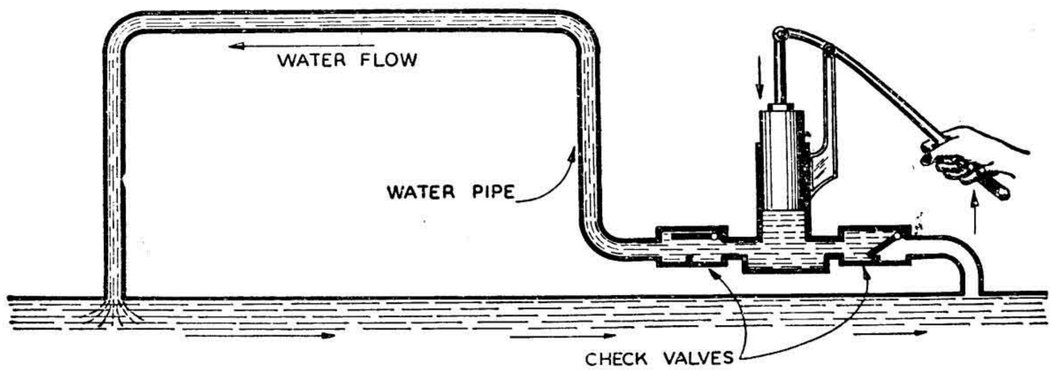
pressure) between the two ends, as there is between the A and B terminals of the battery in figure 21②. This electrical pressure which forces electricity through a circuit is known as "electromotive force."

b. Current.—The A terminal of the battery (fig. 21②) is assumed to have a positive charge of electricity, and the B terminal a negative charge of electricity. Using positive and negative for the designation of the the different kinds of charges gives a convention for fixing the direction of flow of electric current. An electric current is assumed to be a discharge from positive to negative just as water flows from high to low levels. The greater the difference in water level, the greater will be the tendency of the water to seek the same level. The same applies to the electric charge. This difference in charge is termed "difference in potential" or "potential difference," and the terms "high" or "low" potential indicate a large or small charge above or below zero or normal potential.

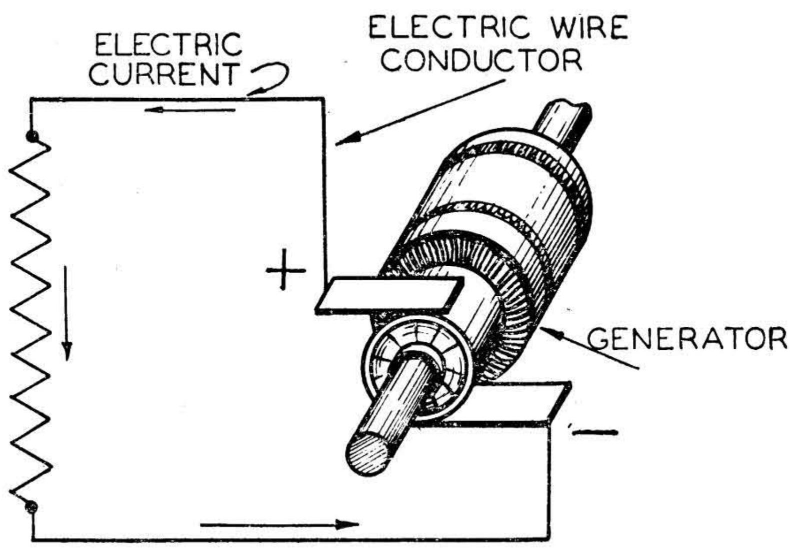
(1) Water will continue to flow through the pipe until there is no longer any difference in pressure. This occurs when the water reaches

the same level at A and B (fig. 21①). Likewise, electric current will continue to flow through the wire until the battery runs down and no longer produces electrical pressure. Before this pressure is lost, the flow of electric current can be stopped by opening the switch just as the flow of water can be stopped by closing the valve.

(2) Water can be forced to flow through a pipe by means of the pressure developed by a pump, as shown in figure 22①, and electricity can be forced to flow through a conductor by means of pressure devel-



① Pressure from pump causes water to flow in pipes.



② Electrical pressure from generator causes current to flow in circuit

FIGURE 22.—Pressure production in hydraulic and electric systems.

oped by an electric generator, as shown in figure 22②. In the water circulating mechanism the "rate of flow" is the amount of water being circulated in gallons per second. In an electrical circuit, the rate of flow may be measured in coulombs per unit of time. A coulomb is the unit of electrical quantity just as the gallon is a unit of quantity of water. When charge is flowing past a given point in a conductor at the rate of 1 coulomb per second, the current is *1 ampere*. Figure 23 shows a comparison of electrical and hydraulic terms.

c. Voltage.—The pressure that makes water flow is measured in pounds per square inch, whereas in an electrical circuit the pressure, or electromotive force, is measured in volts. *A source of electromotive force is said to have 1 volt of electrical pressure when it will establish a current of 1 ampere in a conductor which has a resistance of 1 ohm.*

d. Resistance.—The resistance of a conductor may be compared to the friction occurring between a pipe and the liquid flowing through it. The electrical resistance of a conductor depends upon its size, temperature, length, the kind of material, and whether the conductor is smooth or rough. The electrical resistance of a conductor is measured in *ohms.* A conductor with 1-ohm resistance allows 1 ampere of current to flow when a pressure of 1 volt is applied across its ends. From a practical point of view, it should be remembered that the resistance offered by 1,000 feet of No. 10 B & S gage copper wire (approximately $1/10$ inch in diameter) is almost exactly 1 ohm.

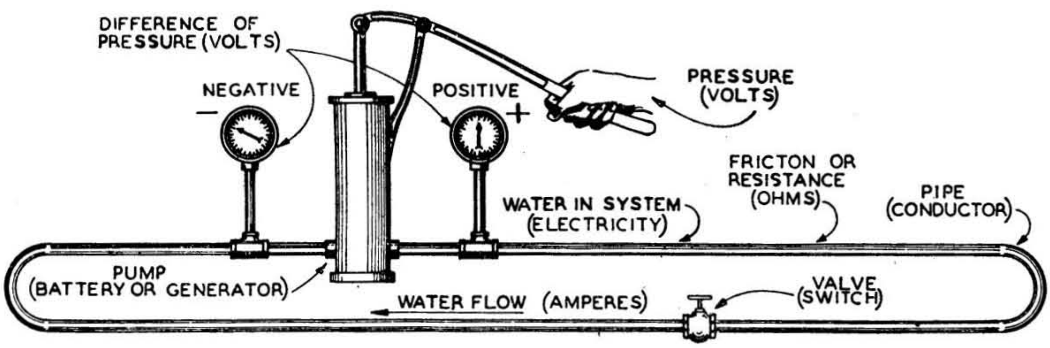


FIGURE 23.—Comparison of hydraulic with electrical terms.

37. Effects of electric current.—An electric current flowing through certain circuits produces various physical, chemical, magnetic, and physiological changes or effects.

a. Heat and light.—Heat is developed to some extent in any conductor through which electricity flows. The amount of heat developed depends upon the amount of current flowing and the resistance of the conductor. If the flow of current and the resistance are sufficient, the conductor may become hot enough to glow with a white heat and give off light as it does in incandescent lamps. The heating effect of electric current is used in electric irons and toasters; and in the airplane it is used in electrically operated carburetor heating devices, airspeed tube heaters, and a variety of other devices. The fuses used in lighting and generator circuits burn out (when the temperature of the fuse wire reaches the melting point) and open the circuits to protect them against possible damage due to overloads. In all cases the heat produced in the conductor represents the use of electrical energy.

b. Chemical effect.—The chemical effect of an electric current may be readily seen by connecting wires to the two terminals of a storage bat-

tery and submerging the free ends in a glass of water in which a little table salt has been dissolved. Current passing through the liquid causes the water to break up into its two component gases, hydrogen and oxygen. The hydrogen gas accumulates in fine bubbles around the negative wire and the oxygen goes to the positive wire. Since there are two volumes of hydrogen produced to one of oxygen, and since the oxygen combines readily with the metal of the positive wire (especially if copper wire is used) formation of gas will appear to take place chiefly around the negative wire, as shown in figure 24. This provides an easy method of distinguishing the positive and negative polarity of live wires and determining whether the current supply is direct or alternating. In the case of alternating current, the same amount of

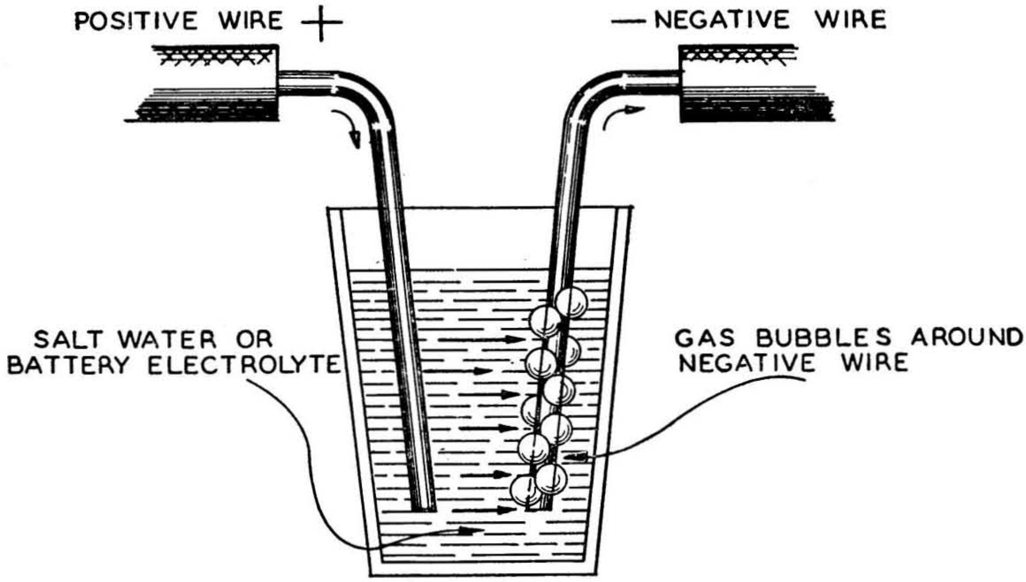


FIGURE 24.—Determining polarity by chemical reaction.

gas will collect around both electrodes because alternating current is constantly changing its direction of flow.

c. Magnetic effect.—The magnetic effect of an electric current may be readily seen by holding a magnetic compass needle near a wire that is carrying current from a battery. The current passing through the wire will cause the compass needle to turn at right angles to the wire. If a current from a battery flows through a coil of insulated wire wound around an iron bar, the bar will have an attraction for other pieces of iron. The iron bar is said to be "magnetized," and the strength and direction of this magnetism is in direct relation to the amount and direction (respectively) of current flowing.

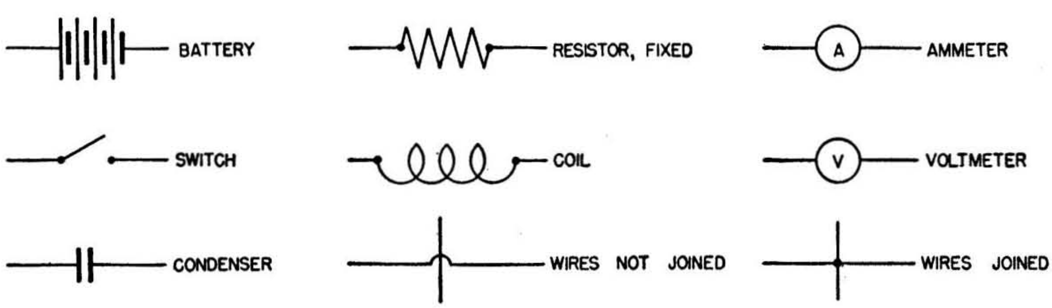
38. Electrical symbols and circuit conventions.—*a.* In circuit diagrams, the battery is represented by alternate long and short lines, a resistance by a zigzag line, connecting wires by plain straight lines, and connections between wires and the battery or the wires and re-

sistances by small circles. These are circuit conventions used in illustrating the theory of electrical circuits by diagrams.

b. Electrical symbols.—In addition to the circuit conventions, certain symbols are necessary for representing electrical quantities in simple mathematical formulas. The standard symbols for these electrical quantities are given in table I.

TABLE I.—*Electrical symbols*

Symbol	Stands for—
I	Rate of current flow in amperes.
E	Electromotive force in volts.
R	Resistance in ohms.
P	Power in watts.
V	Voltmeter.
A	Ammeter.
F	Frequency in cycles per second.



39. Ohm's law.—*a. Definition.*—(1) A definite relationship exists between voltage, current, and resistance. The statement of this relationship is known as Ohm's law. It may be stated as follows: the current in a load unit or circuit is equal to the voltage divided by the resistance. If any two values are known, the other value can be found.

(2) The relationship between E, I, and R may be remembered easily by using the device shown in figure 25. If any one of the symbols in the triangle is covered, the other two will appear in their correct relationship. For example, if E is covered, I and R remain with a multiplication sign between them. Therefore, $E=I\times R$. Any other value may be found by following the same procedure.

b. Application—voltmeter and ammeter.—(1) The voltage and current of a circuit can be measured readily by a voltmeter and an ammeter. Although the two instruments are often similar in external appearance, they differ mainly in their resistances. The voltmeter, containing a coil of many turns of small wire, measures the electrical pressure in volts. This unit is connected directly to the

terminals of the load unit. Never connect a voltmeter in series with the other units in a circuit. The ammeter contains a coil of many turns of small wire connected in parallel with a low resistance conductor. It measures the current flow in amperes and is inserted in series with the circuit so that the current will flow through it. Figure

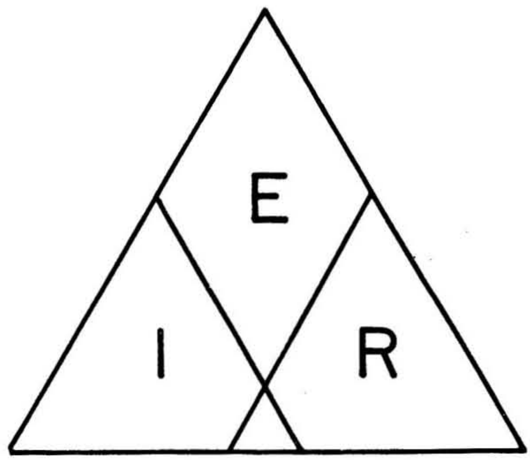


FIGURE 25.—Ohm's law triangle.

26 illustrates the method of connecting an ammeter and a voltmeter in an electrical circuit.

(2) The electrical resistance of a circuit can be calculated by measuring the voltage and current and dividing the voltage in volts by the current in amperes.

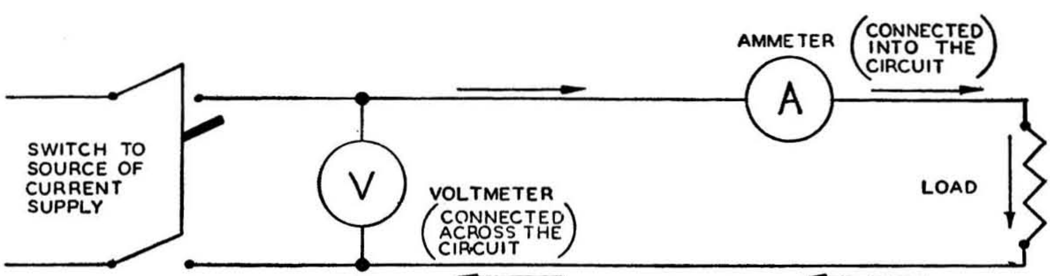


FIGURE 26.—An ammeter and voltmeter connected in an electrical circuit.

40. Electrical power.—*a. Definition.*—Work is done when a force acts on a body and causes it to move. Power is defined as the "time-rate of doing work" and is independent of the total work to be done. The unit of electric power is the "watt." One watt is defined as the power available when 1 ampere of current flows through a circuit under an electrical pressure of 1 volt. Stated as a formula, power=voltage×current; or, using units, watts=volts×amperes. This is sometimes expressed by using symbols, as $P=E\times I$.

b. Example.—The power required from a 12-volt battery to supply a current of 2 amperes to the primary ignition circuit would be

$12 \times 2 = 24$ watts. The watt is often too small a unit for convenient use, so a kilowatt (kw), is frequently used (1 kilowatt=1,000 watts).

c. Some important relations in electrical power are:

1 horsepower=746 watts or 0.746 kilowatt.
1 kilowatt=1.34 horsepower (approximately).
1 kilowatt of power used for 1 hour=1 kilowatt-hour.

41. Sources of current for aircraft purposes.—*a. Storage battery.*—(1) The production of electric current by chemical action is perhaps the oldest known method of producing dynamic electricity.

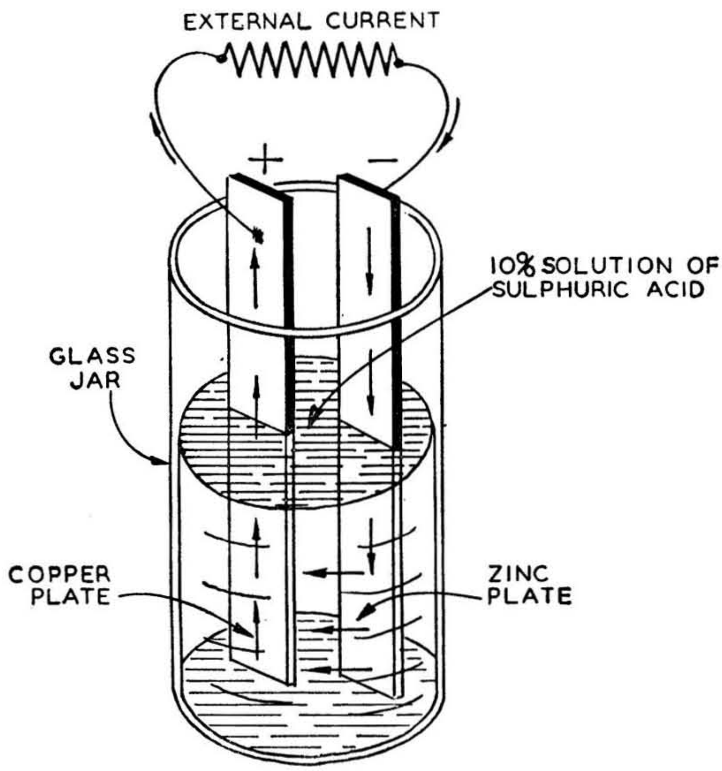


FIGURE 27.—Chemical production of an electrical current.

If two different elements are placed in an acid or alkaline solution which acts chemically upon one element faster than upon the other, a difference in voltage or electrical pressure will be produced. If these two elements are connected externally by a wire, an electric current will flow through the circuit. (See fig. 27.)

(2) The storage cell used on aircraft is a lead-acid cell. It consists of two sets of lead plates, known as "positive" and "negative," placed in an acidproof container containing a solution of sulfuric acid and water. The cell is charged by electrochemical change when a direct current is passed through it from the positive terminal to the negative terminal. When the battery is used as a source of current, the chemical change is reversed and the cell becomes discharged.

A single lead-acid cell gives an electrical pressure of about 2 volts when fully charged. High current output can be obtained for short periods of operation.

b. Generators and magnetos.—(1) If an electric conductor and a magnetic field are moved in relation to each other, an electric current will be generated in the conductor. This is accomplished in the magneto and the generator. The generator is used in the airplane electrical system to keep the battery charged.

(2) Ignition systems utilizing the magneto as the current source are used extensively in aircraft. A magneto is essentially a high-voltage generator.

c. Thermocouple.—The conversion of heat into electrical energy is demonstrated by the thermocouple. Heat applied to the junction of two dissimilar metals—for example, iron and copper—will produce a relatively small voltage across the outer ends, as shown in figure

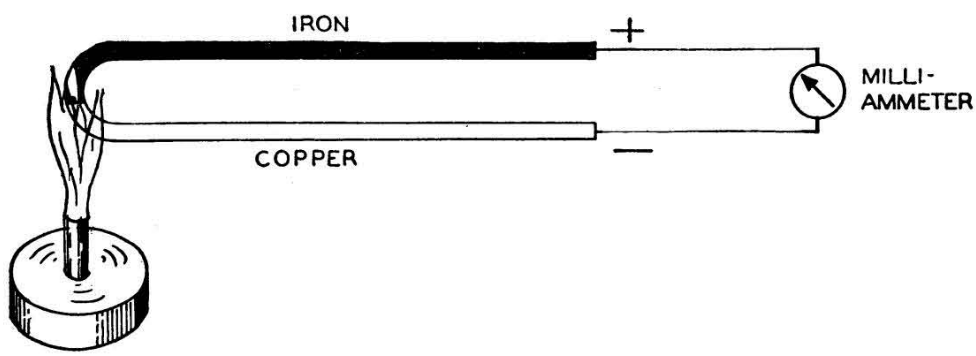


FIGURE 28.—Thermal production of electric current (thermocouple).

28. This voltage is produced because of the difference in heat conductivity between the two metals. It is proportional in value to the difference in temperature between the junction and outer ends of the metals. If the two ends are connected by a wire, a current will flow through the wire from the iron to the copper; and this current can be measured by a milliammeter. The *milliammeter* is a low-range ammeter for measuring thousandths of an ampere.

42. Series and parallel battery circuits.—In order to obtain a larger source of energy than is possible with a single cell, batteries are usually composed of several cells acting in unison. Cells may be connected in series or in parallel to raise the voltage or current to the desired amount.

a. Series circuits.—Battery cells are connected in series when a voltage greater than that produced by one cell is desired. An aircraft electrical system is often designed for 12 volts. Since the single storage cell gives only 2 volts, six cells are connected in series (fig. 29) to give the desired potential of 12 volts. The positive (+) terminal of

one cell is connected to the negative (−) terminal of the next so that the cell voltages, acting in the same direction, are added. Since the current is the same through all of the cells in the series, series connection does not increase the value of the current available. The voltage obtained by series connection is the sum of the voltages of the individual units, and the current obtained is the average current of the individual units.

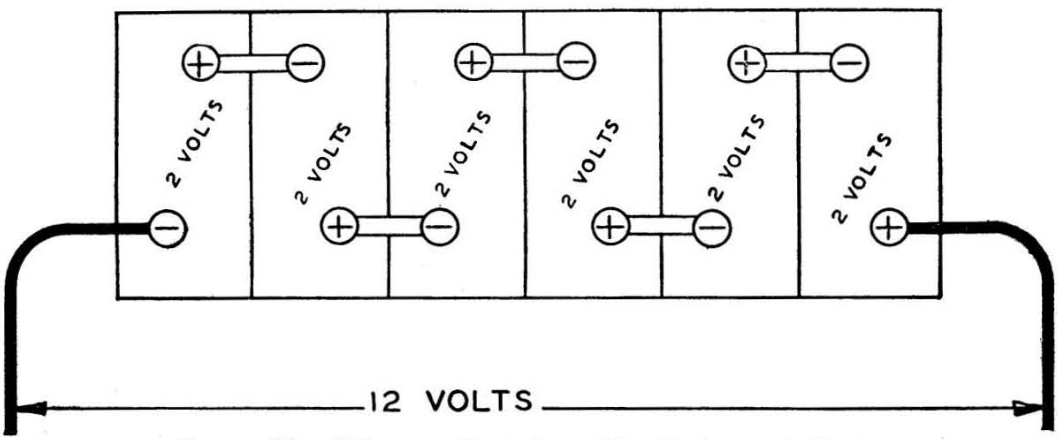


FIGURE 29.—Cell connections for a 12-volt storage battery.

b. Parallel circuits.—Battery cells are connected in parallel when the device being operated requires a current larger than that furnished by one cell, or when a current output equal to that of one cell is desired for long periods of time. The results obtained by parallel connection are the reverse of those obtained by series connection. Like terminals are connected in parallel operation. A comparison of series and

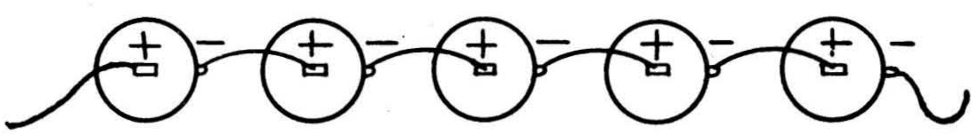


FIGURE 30.—Five dry cells connected in series.

parallel connections is shown in figures 30 and 31. The current obtained by parallel connection is the sum of the currents of the individual units, and the voltage obtained is the average voltage of the individual units.

c. Series-parallel circuits.—When a large current is required at a voltage above that of a single cell, the series-parallel connection is

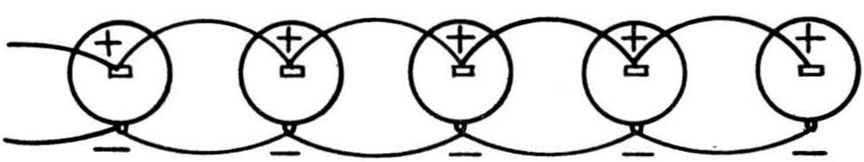


FIGURE 31.—Five dry cells connected in parallel.

used. This arrangement consists of a parallel connection of banks of cells. The cells in each bank are connected in series. An arrangement of three parallel banks, each having five cells connected in series, is shown in figure 32. The total voltage of each bank is the average sum of the voltages of the individual cells in the bank. The currents from each of the banks in parallel add together, while the total voltage of the series-parallel connection is the average voltage of the individual banks. Taking 20 amperes and 1.5 volts as the output of each cell, this arrangement would give 20×3 or 60 amperes at a potential of 1.5×5 or 7.5 volts.

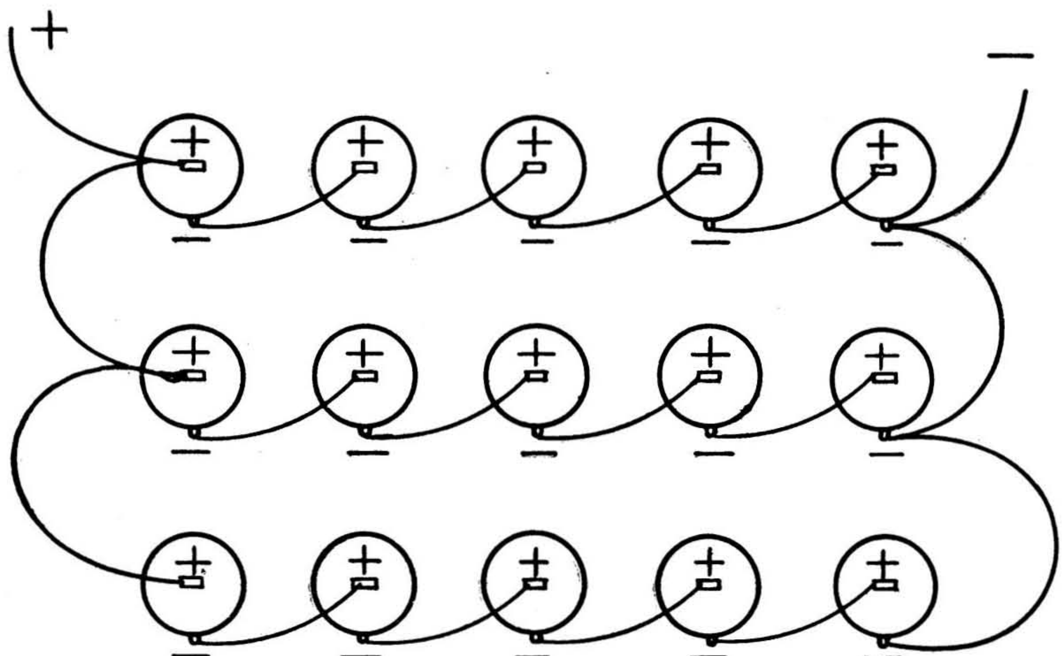


FIGURE 32.—Fifteen dry cells connected in series-parallel circuit.

43. Conductors and insulators.—*a. Definition.*—All substances conduct electricity to some extent, yet all offer resistance to the flow of electricity. Any substance offering comparatively little resistance to the flow of current is known as a "conductor" and is said to have "high conductivity." Substances which offer much resistance to the flow of electricity are known as "nonconductors" or "insulators."

b. The resistance of a conductor depends on several factors. The laws governing the variation of resistance are:

(1) The resistance of a conductor varies directly with its length. When the length of a conductor is increased, the resistance offered by that conductor to an electric current is increased.

(2) The resistance of a conductor varies inversely with its cross-sectional area. An increase in the cross-sectional area of any conductor will decrease the resistance offered by that conductor to a cur-

rent of electricity. Likewise, should the cross-sectional area be decreased, the path over which the current must flow is made smaller and the resistance will increase.

(3) The resistance of a conductor varies with its temperature. A rise in the temperature of a conductor will usually increase the resistance offered by that conductor. However, in the case of some materials a rise in temperature has a negative effect and it will increase the conductivity of the material. This principle is applied in aircraft engines where it is desired to neutralize the heating effect of the engine on parts of the electrical system.

(4) Resistance to an electrical current varies in various materials. The resistance a substance offers to the passage of current depends upon its composition and purity. A few of the most common conductors, in the order of their conductivity are: silver, copper, aluminum, zinc, and brass. Copper, because of its relative cheapness, low resistance, and high tensile strength, is recognized as the best all-around conductor for commercial use. It is used extensively in the construction and wiring of aircraft electrical equipment.

c. Substances offering much resistance to the flow of electricity—for example, glass, mica, bakelite, rubber, porcelain, and fiber—are known as "nonconductors" or "insulators." A conductor covered with insulating material such as rubber, cotton, silk, or enamel is known as an "insulated conductor." A wire is insulated to prevent the current of electricity from flowing onto or away from the wire if it rests against another piece of metal which would provide a path for flow of the current.

44. Condensers.—*a. Purpose.*—A condenser is a device for the temporary accumulation of electrical charge. The condenser receives charge from the circuit and returns most of this charge to the circuit at the proper time. Condensers are used in connection with the ignition and generator systems on aircraft.

b. Construction.—(1) Practically speaking, any two parallel conductors separated by a nonconducting material is a condenser. The nonconducting material is called the "dielectric" of the condenser.

(2) Condensers in current use consist of two plates, sets of plates, or strips of metallic foil, separated from each other by thin pieces or strips of dielectric. The most common dielectrics are mica and waxed paper.

c Operation.—Figure 33 shows a simple condenser connected in a circuit. Before the switch is closed, both plates of the condenser are electrically neutral. When the switch is closed (toward the left) the difference of potential across the plates will become the same as the difference of potential across the battery. The condenser will now be charged. If the load unit is then connected to the terminals of the con-

denser (by closing the switch to the right) the charge in the condenser will be delivered to this load unit.

d. Capacity.—The amount of the charge accumulated by a condenser depends on the difference of potential across the condenser and its capacity. "Capacity" may be defined as the ratio of the quantity of charge to the difference of potential across the condenser. In other words, it is the number by which the difference of potential across the condenser must be multiplied to get the quantity of charge accumulated by the condenser. Capacity is determined by the size and shape of the plates and the thickness and character of the dielectric. It is expressed in farads or microfarads (1 farad = 1,000,000 microfarads).

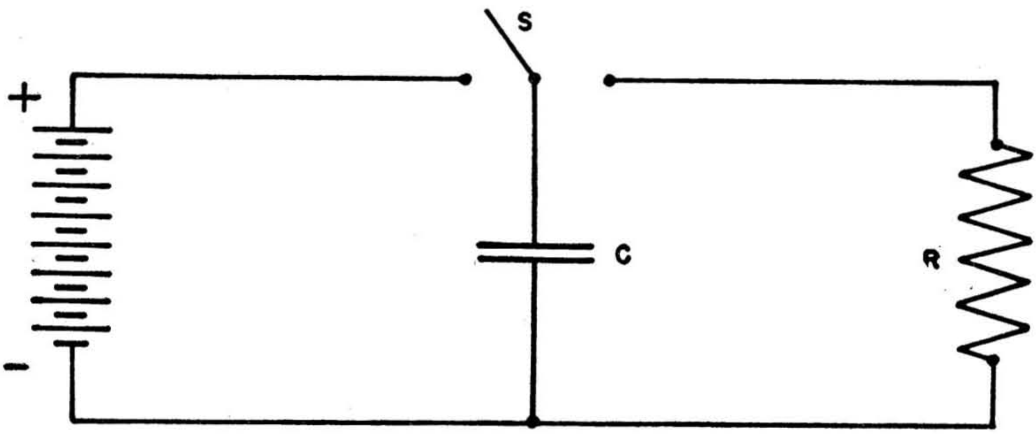


FIGURE 33.—Condenser in a circuit.

SECTION VI

ELEMENTS OF MAGNETISM AND MAGNETIC INDUCTION

45. Nature of magnetism.—*a. General.*—For many centuries it has been known that a certain type of iron ore has the property of attracting small bits of iron and steel. Pieces of this ore, called magnetite, are known as "natural magnets." This property of a material which enables it to attract certain other materials is called "magnetism."

b. Earth's magnetic field.—If a suspended magnet is free to rotate, it will assume a north and south position. For this reason, magnets are used for determining direction. The fact that a compass needle

points north and south indicates that the earth is a huge magnet, with magnetic poles at or near the geographical North and South Poles.

c. Magnetic and nonmagnetic materials.—Iron, steel, nickel, cobalt, and alloys of these elements are materials which exhibit marked magnetic properties. Materials such as copper, aluminum, and zinc, which are not susceptible to magnetism, are known as nonmagnetic materials. Some magnetic alloys contain nonmagnetic elements.

d. Magnets.—Magnets may be made either by stroking bars of steel in one direction with a magnet or by passing electric currents around the bars. For commercial purposes, artificial magnets are magnetized by an electric current. Magnets produced by artificial means are said to have been magnetized by induction. Magnetic induction takes place through all nonmagnetic materials, whether they are solids, liquids, or gases. In other words, nonmagnetic materials are not magnetic insulators.

46. Permanent magnets.—*a.* A hard steel bar when magnetized will remain so indefinitely unless it is subjected to heat or jarring; while soft iron, although more readily magnetized, loses practically all of its induced magnetism almost immediately upon removal of the charging influence. Consequently, steel and steel alloys, such as nickel-steel, are used in the production of permanent artificial magnets, while soft iron is used as the core of electromagnets for temporary magnetization.

b. Magnetic field around bar magnet.—(1) The bar magnet is a rectangular steel bar the strength (power of attracting magnetic materials) of which is concentrated at each end. Consequently, the ends of the bar magnet form the poles. The pole which always points to the earth's magnetic North Pole when the magnet is suspended freely, is called the north-seeking or simply the north (N) pole of the magnet. The other pole of the magnet is called the south (S) pole. The poles of the magnet are of equal strength, and the fact that fragments of a magnet always have two poles indicates that magnetism is a condition which prevails throughout the whole mass of the magnet.

(2) The magnetic field around a bar magnet may be seen readily by placing a piece of paper over a bar magnet and sprinkling iron filings over the paper. The magnetic force will arrange the filings in curved lines running from one end of the magnet around to the other end, as shown in figure 34. The conventional method of representing the field around magnets is shown in figure 35. The region surrounding a magnet through which magnetic lines of force travel from the north pole to the south pole is known as the "magnetic field"

of the magnet. The strength of this field depends upon the amount of pull per unit area of the pole and is usually measured by a certain number of magnetic lines per unit of area.

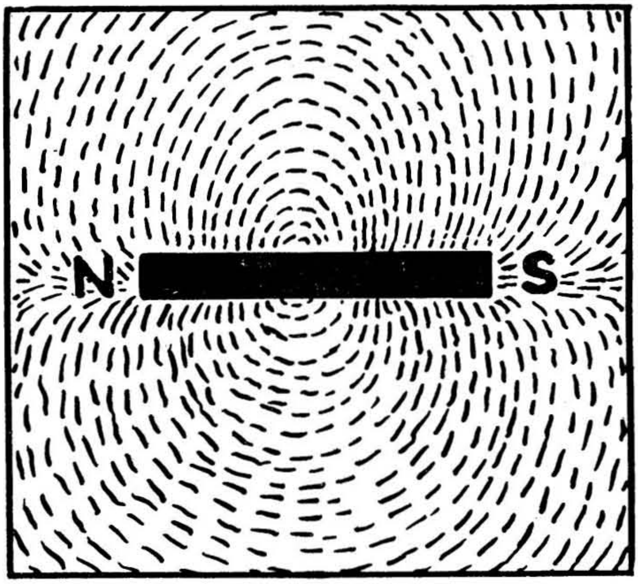


FIGURE 34.—Magnetic field of a magnet shown by iron filings.

c. Laws of magnetism.—When two magnets are brought together, the following reactions will always take place:

(1) Unlike poles will always attract each other.

(2) Like poles will always repel each other.

(3) The closer the poles are to each other, the stronger the force

FIGURE 35.—Magnetic field around bar and horseshoe magnets.

of attraction or repulsion. This force decreases rapidly as the poles are moved apart.

(4) A magnetic field will be set up between the poles. If the poles are unlike, the field between the poles will be as shown in figure 36①. The field between like poles is shown in figure 36②.

d. Horseshoe magnets.—Permanent magnets are found in two forms: the bar magnet, previously discussed, and the horseshoe mag-

net. The horseshoe magnet is simply a magnetized iron bar made in the shape of a **U** or horseshoe. This creates a magnetic field of greater intensity because each magnetic line of force emerging from the north pole returns to the south pole of the magnet through a much shorter distance than that traveled by the lines of force of a bar magnet. If the strength of the field between the two poles of a horseshoe magnet is tested, it is found to be more intense than that of a bar magnet of equal strength. In a horseshoe magnet not only is the path of each line of force shortened, but more lines exist.

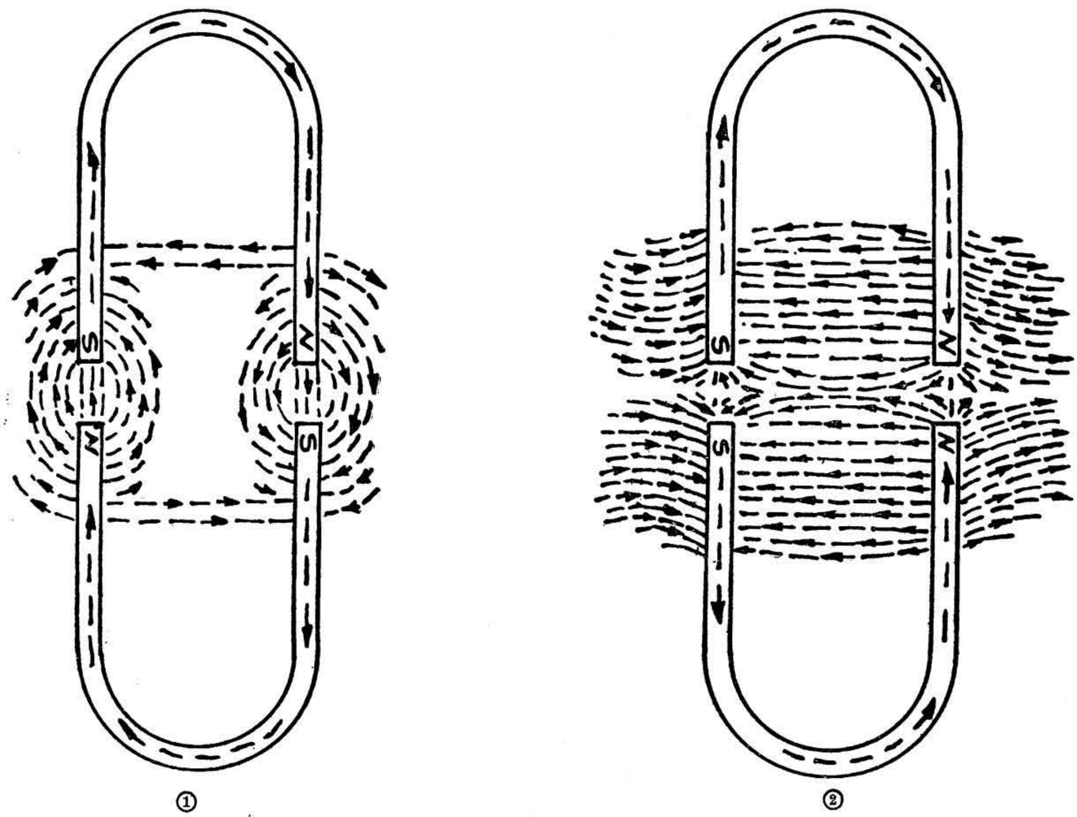


FIGURE 36.—Magnetic fields between like poles (right) and unlike poles (left).

47. Magnetic circuit.—*a.* It is generally believed that magnetism acts in the nature of a stream or current. This flow of magnetism is called "magnetic flux" and is represented by lines of force which always flow out of the North Pole of a magnet and around into the South Pole, forming a complete circuit. The relative strength of the field depends upon the number of the magnetic lines of force existing in the magnetic circuit.

b. Comparison to electrical circuit.—In an electrical circuit, if a conductor and a resistance are connected between the positive and negative poles of a battery and the resistance is decreased, the current strength is increased. In the case of a magnet, if the length of the paths from the North Pole to the South Pole is decreased by bend-

ing the magnet into the form of a horseshoe, the number of lines of force is greatly increased. If a piece of soft iron or other magnetic material is inserted between the poles of a horseshoe magnet in the space now filled with air, the number of lines of force existing in the circuit between the North and South Poles is considerably increased. This is analogous to decreasing the resistance of an electrical circuit by substituting a conductor of lower resistance for one of higher resistance.

(1) It follows from the previous discussion that the strength of the magnetic flux depends upon the material of the completed magnetic circuit and the strength of the magnet. This corresponds to the fact that the current strength in any given cross section of an electrical conductor depends upon the resistance of the closed electrical circuit and the electromotive force applied. From these facts, it may be seen that an equation identical in form to Ohm's law may be applied to the complete magnetic circuit. This states that *the flux for any given magnetic circuit is equal to the "magnetic pressure" producing the flux divided by the opposition overcome in establishing the flux.*

(2) There are two important ways in which the analogy of the magnetic circuit to an electric circuit is incomplete. First, a magnetic circuit can never be entirely opened. A magnetic field must exist at all times in the vicnity of a magnet, while a switch placed in an electrical circuit stops the flow of electricity when it is opened. Second, magnetic flux is not strictly analogous to current because current is rate of flow of electricity, while magnetic flux is more nearly a state or condition of the medium in which it is established.

48. Electromagnets.—*a. Magnetic field around a current-carrying conductor.*—(1) Magnetism produced by an electrical current is called *electromagnetism.* A wire or any other conductor carrying an electric current will have a magnetic field set up around it. The strength of this field is proportional to the amount of current the conductor carries. This fact is the basis for the relation between electricity and magnetism. The magnetic field thus produced is arranged in concentric circles around the wire, as shown in figure 37, and flows clockwise for the observer looking along the wire in the direction the current is flowing.

(2) The direction of the magnetic field around a conductor can be determined by a pocket compass. The magnetic needle, if held above

FIGURE 37.—Magnetic field surrounding an electrical conductor.

or below a wire carrying a direct current, will turn across the wire, with the north end of the compass needle pointing around the wire in the direction of the magnetic lines of force, as shown in figure 38. By determining the direction of the magnetic field around the wire, the direction of the current flowing in the wire may also be determined.

b. Magnetic field around current carrying loop.—If the wire is coiled into a loop, it will be found that the concentric lines of force go

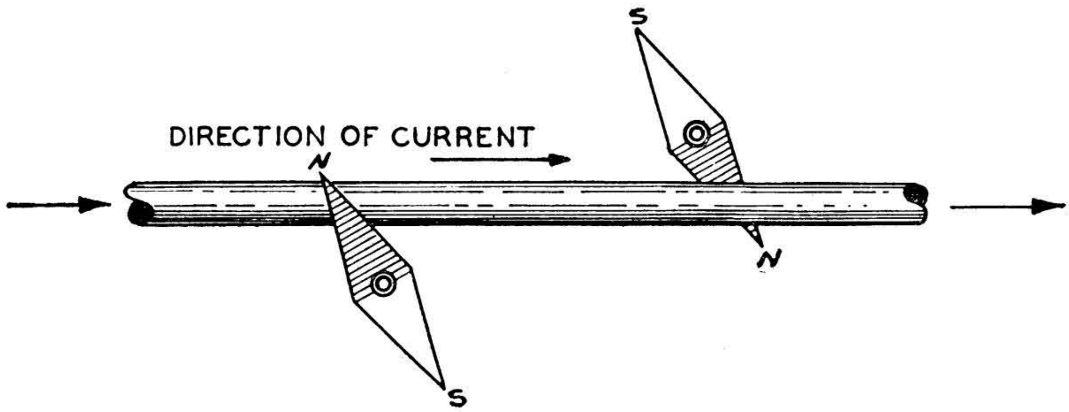


FIGURE 38.—Using a compass to determine in which direction the current is flowing.

in the same direction through the center of the loop, as shown in figure 39. If two loops are placed close together, nearly all the lines of force will merge and go around the two wires together, as shown in figure 40.

c. Magnetic field around an air-core coil.—When a number of turns of insulated wire are wound into a coil, as shown in figure 41, nearly

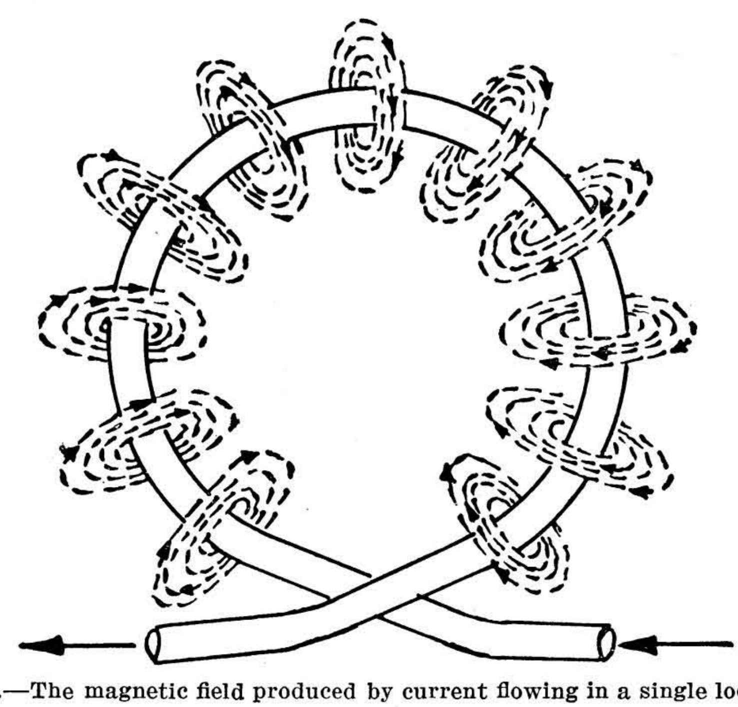


FIGURE 39.—The magnetic field produced by current flowing in a single loop of wire.

all the lines of force will enter one end of the coil, pass through it, leave the opposite end, and return outside the coil to complete the circuit. Thus a coil carrying an electric current has essentially the same kind of magnetic field as a bar magnet. It has a north pole where the lines of force leave the coil, and a south pole where the lines of force enter the coil.

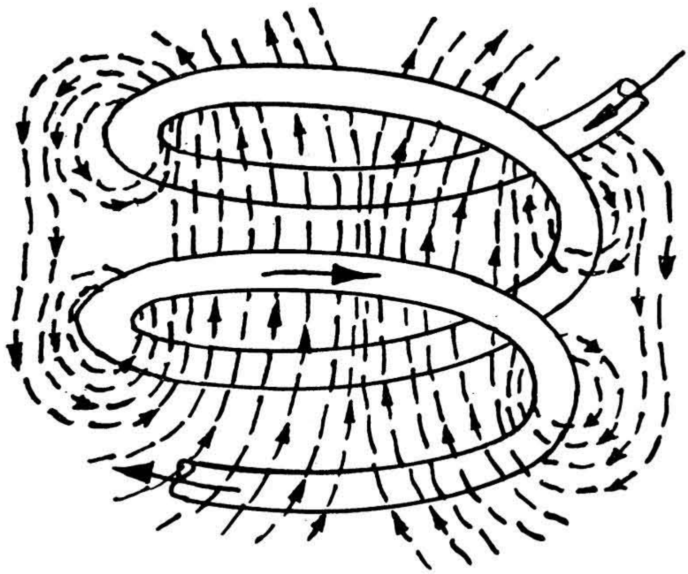


FIGURE 40.—Magnetic field produced by current flowing in two adjoining loops of wire.

d. Horseshoe electromagnet.—The strength of an electromagnet can be greatly increased by giving it such form that the magnetic lines can remain in iron throughout their entire length instead of remaining in air as they do in figure 41. For this reason, electromagnets are usually built in the horseshoe form and provided with an armature, through which a nearly complete iron path for the lines of force is established.

(1) *Permeability.*—The ability of the material between the poles of a magnet to conduct magnetism has a marked effect on the strength

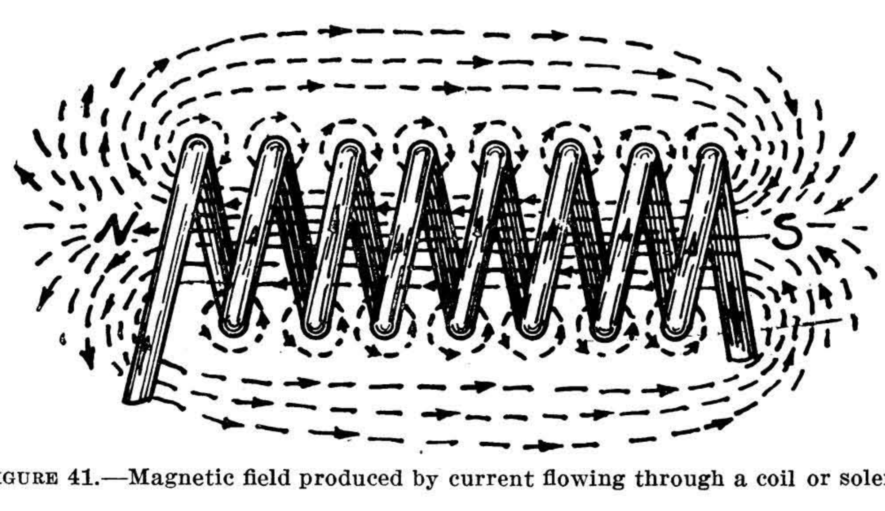


FIGURE 41.—Magnetic field produced by current flowing through a coil or solenoid.

of the field. This ability to conduct magnetism is called "permeability." Permeability of a material is expressed as the ratio of the strength of a magnetic field, with that material forming its entire core, to the strength of the field if air is used as the core. Nonmagnetic materials all have a permeability of very nearly 1. All magnetic substances have permeabilities much greater than 1, the value depending upon the character of the substance and the magnetizing force. The strength of an electromagnet varies with the material used for its core.

(2) *Saturation.*—Magnetic materials tend to become magnetically saturated when conducting considerable magnetism; that is, magnetic materials can pass only a certain number of lines of force. When the magnetizing force is such that the magnetic material is saturated with magnetism, additional magnetizing force will not produce much increase in magnetic field strength.

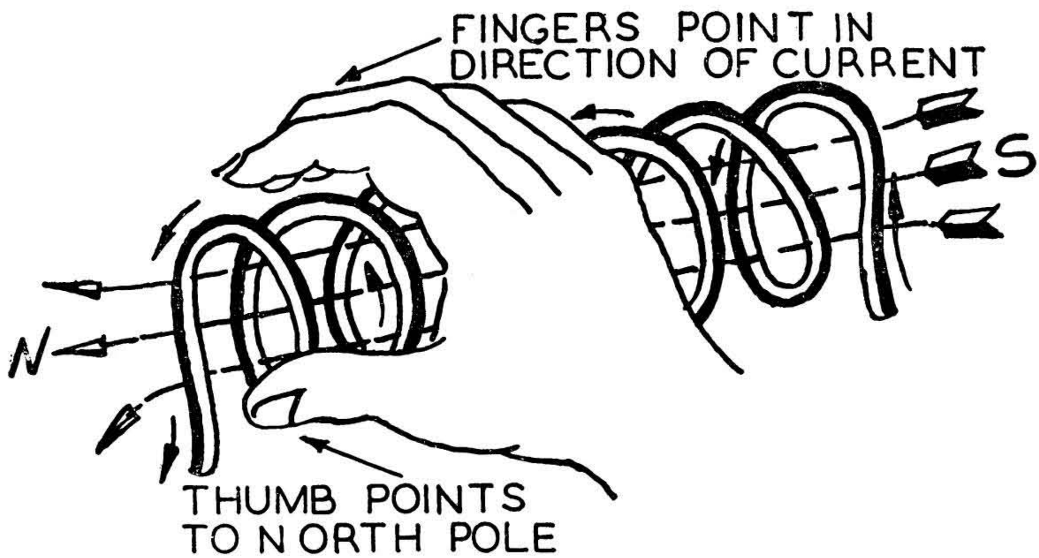


FIGURE 42.—Determining polarity of an electromagnet.

(3) *Polarity.*—A simple method for determining the polarity of an electromagnet, if the direction of the current is known, is to grasp the coil in the right hand with the fingers pointing around the coil in the direction the current is flowing. With the hand in this position, as shown in figure 42, the thumb will point in the direction of the magnetic lines of force or along the core to the north pole. The polarity of an electromagnet may also be quickly determined by holding a compass near its poles. The north end of the needle will point to the south pole of the electromagnet.

49. Relation between current and field intensity.—Field intensity may be defined as the magnetizing force of a coil. This magnetizing force is dependent upon the amount of current flowing through the winding and the number of turns in the coil. When

the current strength in the coil is increased, it is found that the intensity of the magnetic field is increased proportionately. Likewise, if the number of turns in the coil is increased, the intensity of the magnetic field increases also. Therefore, the magnetic field intensity is directly proportional to the current flowing in the winding and the number of turns in the coil. The magnetic pull of an electromagnet depends chiefly upon the number of amperes multiplied by the number of turns in the winding, or the total number of *ampere turns* (see fig. 45) producing the magnetism.

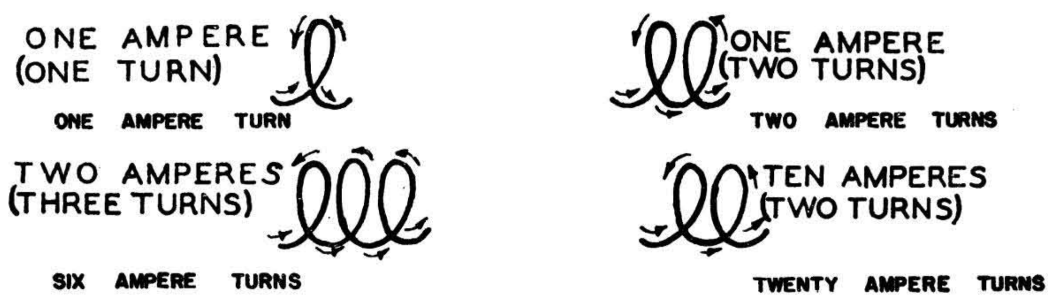


FIGURE 43.—Magnetizing force of a coil depends upon amperes and number of turns in the coil.

50. Electromagnetic induction.—*a. General.*—Since it is true that a current flowing in a conductor produces a magnetic field around the conductor, it is also true that setting up a magnetic field around a conductor momentarily produces an electric current when the conductor is in a closed circuit.

b. Induced current.—The process of generating a current in this manner is known as "induction," and the current thus produced is called "induced current." If the current is generated by magnetism alternating in direction with respect to the conductor, the induced current will also be alternating in direction with as many reversals per second through the wire as there are reversals of magnetism around it. Such a current is called "alternating current," and is usually abbreviated "a-c."

(1) A magnetic field may be used to induce current in a wire, either by cutting the magnetic field with the wire, as is done in a stationary-field-type magneto or a generator, or by cutting the wire with a moving magnetic field, as in the inductor type magneto and in the induction coil.

(2) The method by which a magnetic field is set up around a conductor and the relative direction of the induced current are shown in figure 44. N and S represent the north and south poles of a magnet, and W a wire cutting through a magnetic field between N and S in a downward direction. The magnetic lines of force between N and S tend to act like rubber bands under tension, becoming dis-

torted by the moving wire, as shown in figure 44 ②. The distorted lines of force crowding ahead of the moving conductor or wire create a field of greater intensity on one side of the conductor than on the other. This has the effect of setting up a magnetic whirl around the conductor in a counterclockwise direction, as in figure 44 ③, thereby inducing a voltage and current flowing out of the conductor as indicated.

(3) If the wire is stationary and magnetic lines are made to cut the wire, the effect will be the same. In either case, the direction of

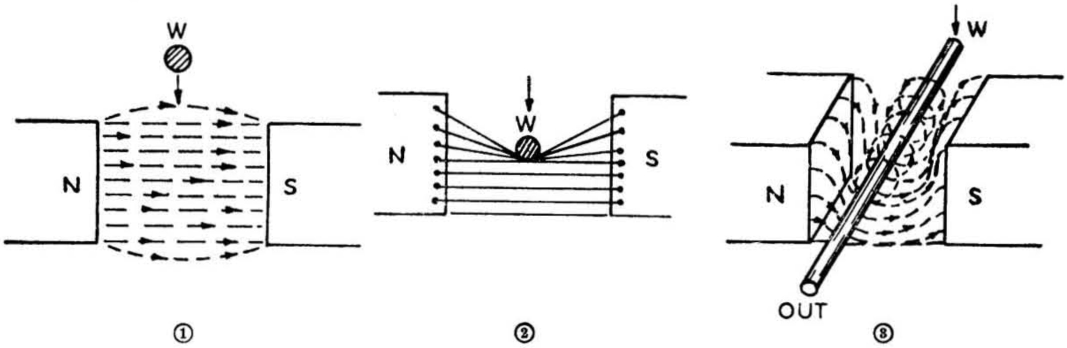


FIGURE 44.—Current produced by electromagnetic induction.

the current set up in the wire will depend upon the direction in which the wire cuts the magnetic lines of force. Furthermore, the amount of current and voltage thus produced will depend upon the resistance of the wire, the strength of the magnetic field, and the speed at which the magnetic lines of force are cut.

(4) *Right-hand rule.*—An easy method for determining the relation between the induced current, the direction of magnetism, and the movement of the wire through the magnetic field is to extend the thumb and the first two fingers of the right hand so that they are at right angles to each other. If the first finger is pointed in the direction of the magnetic field from N to S, as in figure 45, and the thumb in the direction of motion of the conductor with respect to the field, the second finger will point in the direction of the induced current.

c. Inductance.—Electrical circuits containing one or more coils possess a property called inductance which tends to retard the establishment of current in the circuit, or to oppose a change in the value of an existing current. The effects of inductance may be compared to those of inertia. Time is required to bring a flywheel "up to speed" because of its inertia; and when in motion, the wheel opposes an increase or decrease in its speed. Likewise, time is required for the establishment of current in a circuit because of its inductance. The inductance also causes a retardation in the increase or decrease of an existing current. The inductance of a circuit depends directly upon the magnetic properties of its parts. The greater the total

amount of magnetism created by each ampere of current which flows in the circuit, the greater is the inductance of the circuit. An electrical device which employs magnetism in its operation introduces considerable inductance into a circuit of which it is a part. Therefore, such a device is called an "inductive unit."

d. Self-induction.—(1) When current is increasing in a coil, a magnetic field is produced around each turn of the coil. If the coil contains an iron core, the core will be magnetized and a stronger field will be produced. As this field is being set up, the magnetic lines of force cross the turns of the coil. This produces an induced current which is opposite in direction to (and therefore opposes) the current which is flowing in the coil. The production of current in this manner is

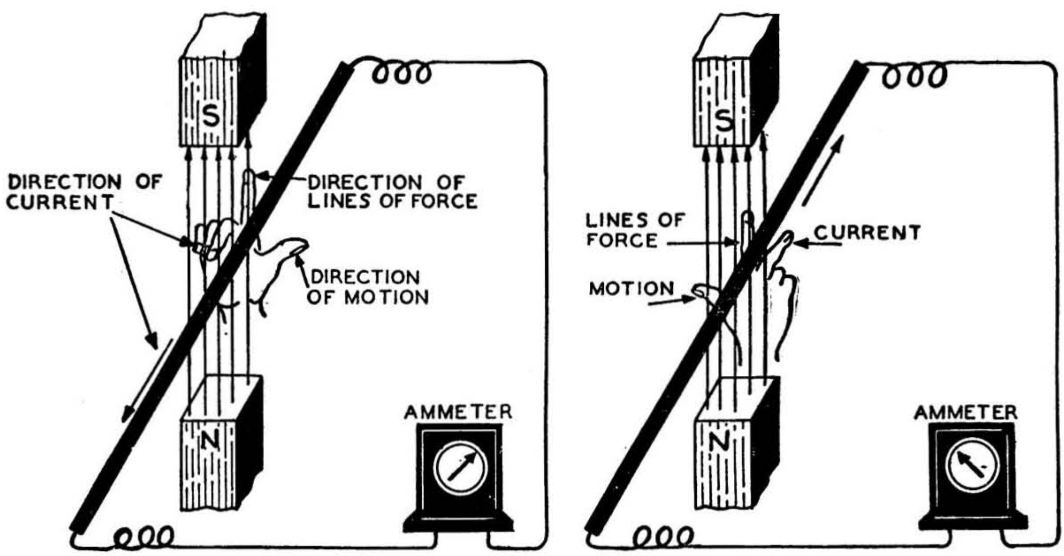


FIGURE 45.—Determining direction of induced current (right-hand rule).

called "self induction." As soon as the current in the coil reaches its maximum value, the self-induced current disappears.

(2) If the circuit is broken (after the current reaches its maximum value), the magnetic field around the coil collapses. The magnetic lines of force will again cross the turns of the coil, and a momentary current will be induced in the coil by self induction. This current will tend to flow in the same direction as the original current. As the circuit has been broken, there is no place to which this current can flow. Therefore, for a moment, one end of the coil will be very highly charged negatively, and the other end will be very highly charged positively. The difference of potential across the ends of the coil may thus reach a very high value for a short period of time. This fact is the basic principle of ignition systems. If a spark plug is connected in parallel with the coil, the momentary high difference of potential across the electrodes of the plug will cause arcing between them.

e. Mutual induction.—The induction of an electromotive force (emf) in one coil by a change in the magnetism of a neighboring coil is called "mutual induction." In figure 46 two neighboring circuits are shown, one with and one without a battery. When the current in the primary circuit is started by closing the switch, magnetic lines of force due to this current will link coil 2 of the secondary circuit. As these magnetic lines of force cut coil 2, an induced electromotive force and an induced current are set up in coil 2. The current in the secondary coil lasts only while the current in the primary coil and the magnetic field around it are changing. As soon as the current in coil 1 ceases to increase, the current in coil 2 disappears. When the current in the primary circuit ceases to flow, the magnetic field of coil 1 col-

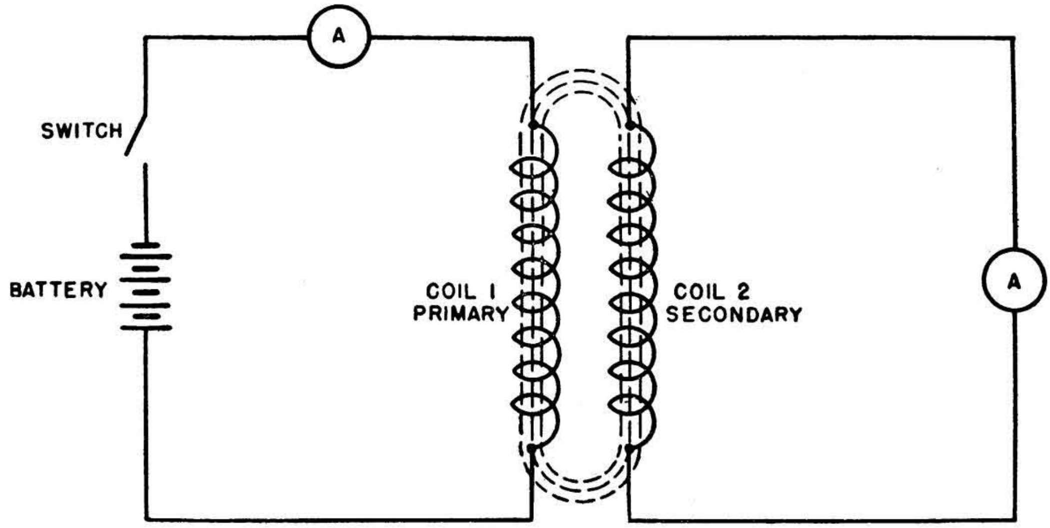


FIGURE 46.—Mutual inductance.

lapses and the lines of force which link coil 2 disappear. During their disappearance there is a momentary electromotive force and current in the secondary coil. In most ignition apparatus, the two coils (which are made of insulated wire) are wound around a common core. Most of the emf induced in the secondary coil is due to loss of magnetism of the core.

f. Alternating currents.—If the amount of magnetic flux associated with a coil is varied by any process whatsoever, an emf is induced in the coil. Figure 47 illustrates a simple method for variation of magnetic flux in a magnetic circuit. A permanent magnet is mounted within the gap of an unmagnetized iron yoke so that the magnet may be rotated. This forms a magnetic circuit composed of the magnet and the yoke. A coil which is mounted on the iron yoke is linked with the magnetic circuit. As the magnet rotates from the position shown in figure 47, the strength of the magnetic field around the yoke decreases. As the magnetic lines of force disappear, they cut the turns

of the coil, and an emf is induced in the coil. When the magnet has rotated 90° from the position shown in figure 47, the effect of one magnetic pole on the yoke is canceled by the other. As the magnet continues to rotate, a magnetic field is again built up around the yoke, with the magnetic lines of force reversed in direction. While this field is building up, the magnetic lines of force again cut the turns of the coil, and an emf in the opposite direction is induced in the coil. A similar change in the direction of the magnetic field around the

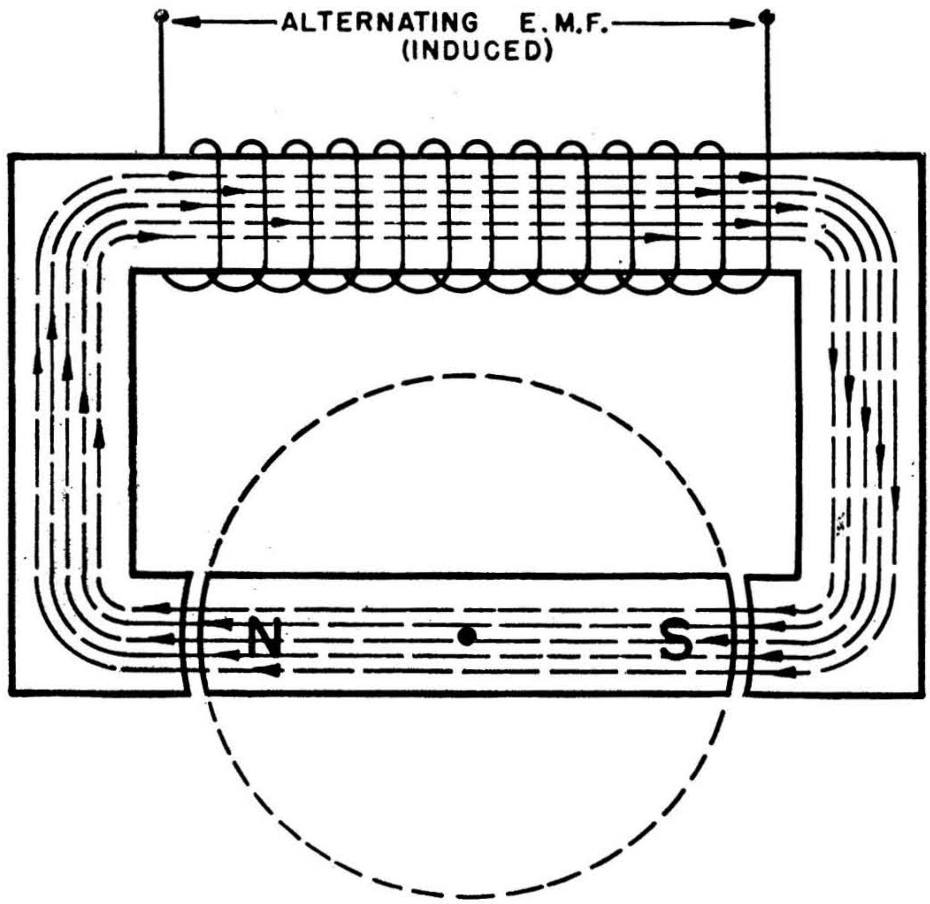


FIGURE 47.—Production of an alternating circuit.

yoke occurs after the magnet has rotated 270° from the position shown in figure 47. Since the magnetic field reverses direction twice each revolution, the emf induced in the coil will change direction or "alternate" twice during each revolution of the magnet.

(1) *Frequency.*—The reversal of the magnetic flux causes the induced current to flow in opposite directions at regular intervals. When the current rises from zero to a maximum in one direction, returns to zero, rises to a maximum in the other direction, and returns to zero again, it has completed a *cycle*. This cycle is repeated over and over. The number of times that the cycle is repeated each second is known as the "frequency."

(2) *Ohm's law applied to alternating current.*—In an alternating current circuit the current and voltage increase to a maximum in one direction, decrease to zero, increase to a maximum in the other direction, then decrease to zero. In some circuits, the voltage and current reach their maximum value at the same instant. Ohm's law in its simplest form may be applied to a circuit of this type. If (because of peculiarities of the circuit) the current reaches its maximum value before or after the voltage reaches its maximum value, the simple form of Ohm's law must be changed to include a factor of correction.

Appendix

Table I.—*Metric system*

Length

10 millimeters (mm)	=1 centimeter (cm).
100 centimeters	=1 meter (m).
1,000 meters	=1 kilometer (km).

Volume

100 cubic millimeters	=1 cubic centimeter.
1,000 cubic centimeters	=1 liter (L).

Weight

1,000 milligrams (mg)	=1 gram (g).
1,000 grams	=1 kilogram (kg).

Table II.—*Conversion tables—English to metric*

Length

1 inch	=2.54 centimeters.
1 foot	=30.48 centimeters.
1 yard	=.9144 meter.
1 mile	=1.609 kilometers.

Volume

1 quart	=.9464 liter.
1 gallon	=3.785 liters.
1 cubic foot	=28.32 liters.

Weight

1 ounce	=28.35 grams (g or gm).
1 pound	=.4536 kilogram.
1 ton (short)	=907.2 kilograms.
1 ton (long)	=1,016.05 kilograms.

TABLE III.—*Decimal Equivalents of Fractions*

Fraction	Decimal equivalent	Fraction	Decimal equivalent
1/32	0. 03125	17/32	0. 53125
1/16	. 0625	9/16	. 5625
3/32	. 09375	19/32	. 59375
1/8	. 125	5/8	. 625
5/32	. 15625	21/32	. 65625
3/16	. 1875	11/16	. 6875
7/32	. 21875	23/32	. 71875
1/4	. 25	3/4	. 75
9/32	. 28125	25/32	. 78125
5/16	. 3125	13/16	. 8125
11/32	. 34375	27/32	. 84375
3/8	. 375	7/8	. 875
13/32	. 40625	29/32	. 90625
7/16	. 4375	15/16	. 9375
15/32	. 46875	31/32	. 96875
1/2	. 5	1	1. 000

TABLE IV.—*Commonly used equations*

Area of a circle=diameter×3.1416.
B.t.u.×778=foot-pounds.
Capacity of a cylindrical tank=diameter^2×length×.0034.

$$\text{Capacity of a rectangular tank}=\frac{\text{length}\times\text{width}\times\text{depth.}}{231}$$

Circumference of a circle=diameter×3.1416.

$$\text{Efficiency (in percent)}=\frac{\text{output}\times 100.}{\text{input}}$$

Force=pressure×area.
Gallons (British imperial)×1.201=U. S. gallons.
Gallons (U. S.)×231=cubic inches.
Gallons (U. S.)×3.7854=liters.
Horsepower×33,000=feet=pounds per minute.
Horsepower×746=watts.
Inches of mercury×.49116=pounds per square inch.
Inches of mercury×25.4=millimeters of mercury.
Kilograms×2.205=pounds.
Knots×1.152=miles per hour.
Liters×1.057=quarts.

$$\text{Mechanical advantage (force)}=\frac{\text{resistance.}}{\text{effort}}$$

Miles×1.609=kilometers.
Millimeters of mercury×.01934=pounds per square inch.
Momentum=mass×velocity.
Pounds×.4536=kilograms.
Pounds per square inch×51.7=millimeters of mercury.
Power (in watts)=volts×amperes.
Torque=force applied×length of lever arm.
Volts=amperes×ohms.

TABLE V.—*Approximate weights of common liquids*

	Pounds per U. S. gallon
Anti-icer fluid (iso-propyl alcohol)	6.7
Ethylene glycol	9.1
Gasoline	6
Hydraulic fluid (petroleum base)	7.5
Oil (lubricating)	7.5
Water	8.337

TABLE VI.—*Centigrade-Fahrenheit conversion table*

C.	F.	C.	F.
−40° =	−40°	160° =	320°
−30° =	−22°	170° =	338°
−20° =	−4°	180° =	356°
−10° =	14°	190° =	374°
0° =	32°	200° =	392°
10° =	50°	210° =	410°
20° =	68°	220° =	428°
30° =	86°	230° =	446°
40° =	104°	240° =	464°
50° =	122°	250° =	482°
60° =	140°	260° =	500°
70° =	158°	270° =	518°
80° =	176°	280° =	536°
90° =	194°	290° =	554°
100° =	212°	300° =	572°
110° =	230°	310° =	590°
120° =	248°	320° =	608°
130° =	266°	330° =	626°
140° =	284°	340° =	644°
150° =	302°	350° =	662°

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BY ORDER OF THE SECRETARY OF WAR:

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Chief of Staff.

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The Adjutant General.

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(For explanation of symbols, see FM 21–6.)

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